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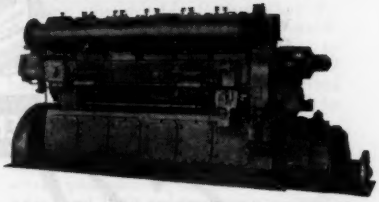

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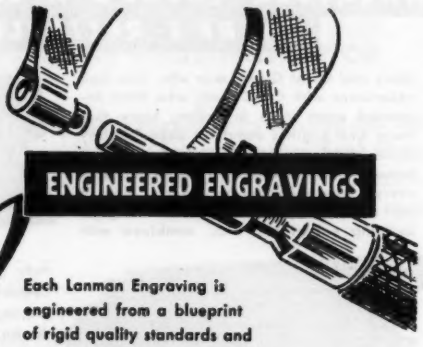

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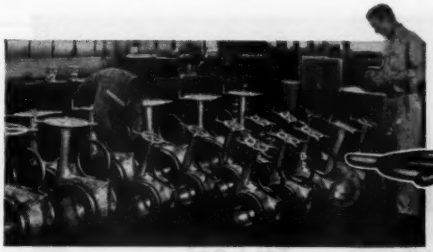

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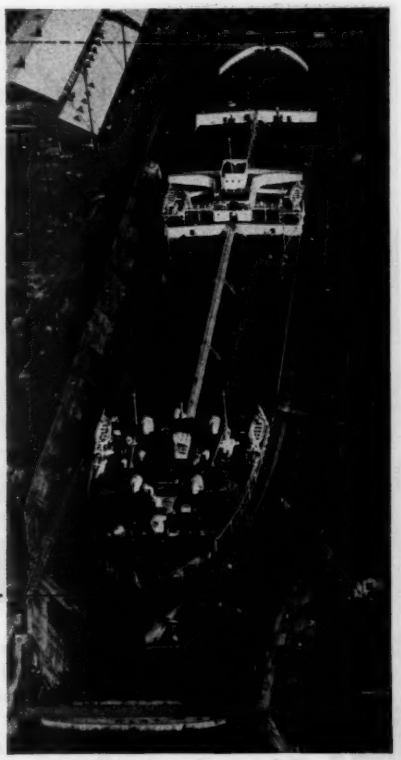

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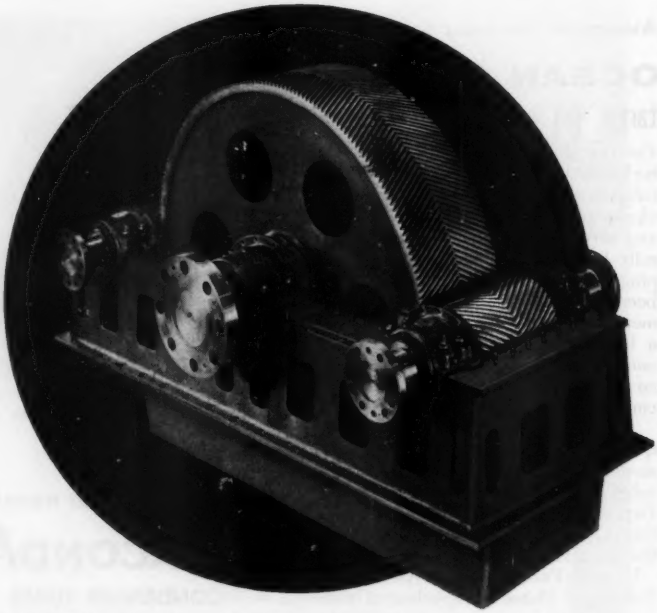

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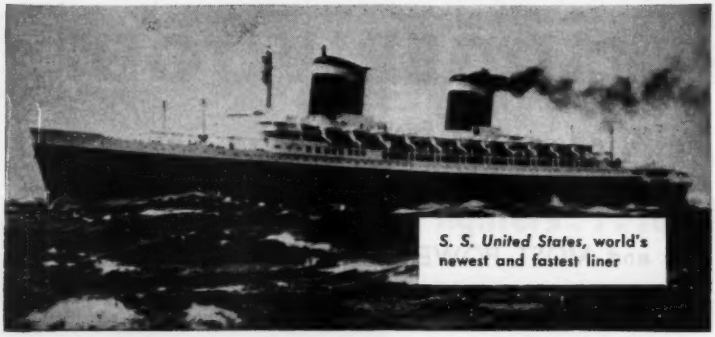

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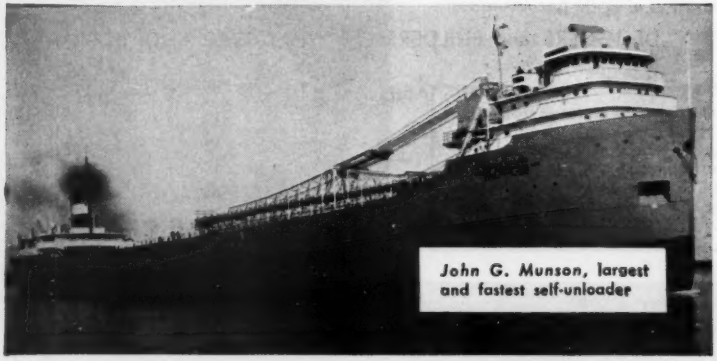

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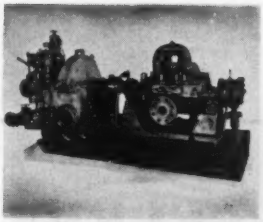
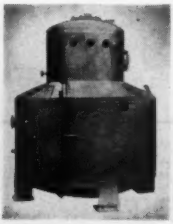
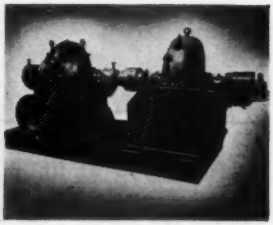

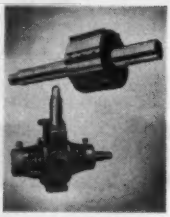
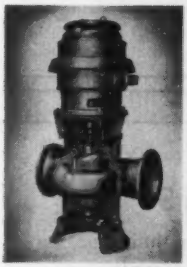
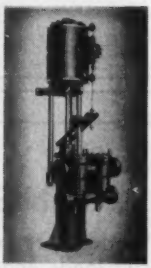
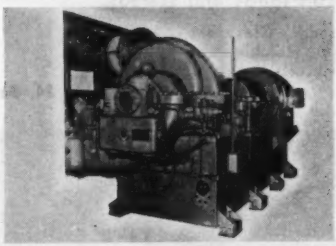
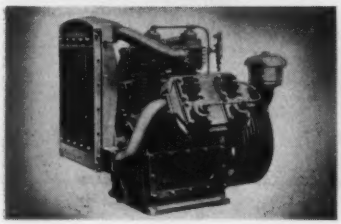

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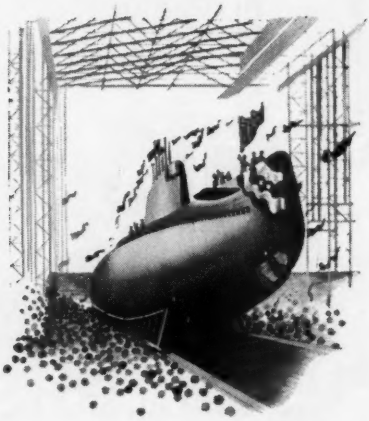

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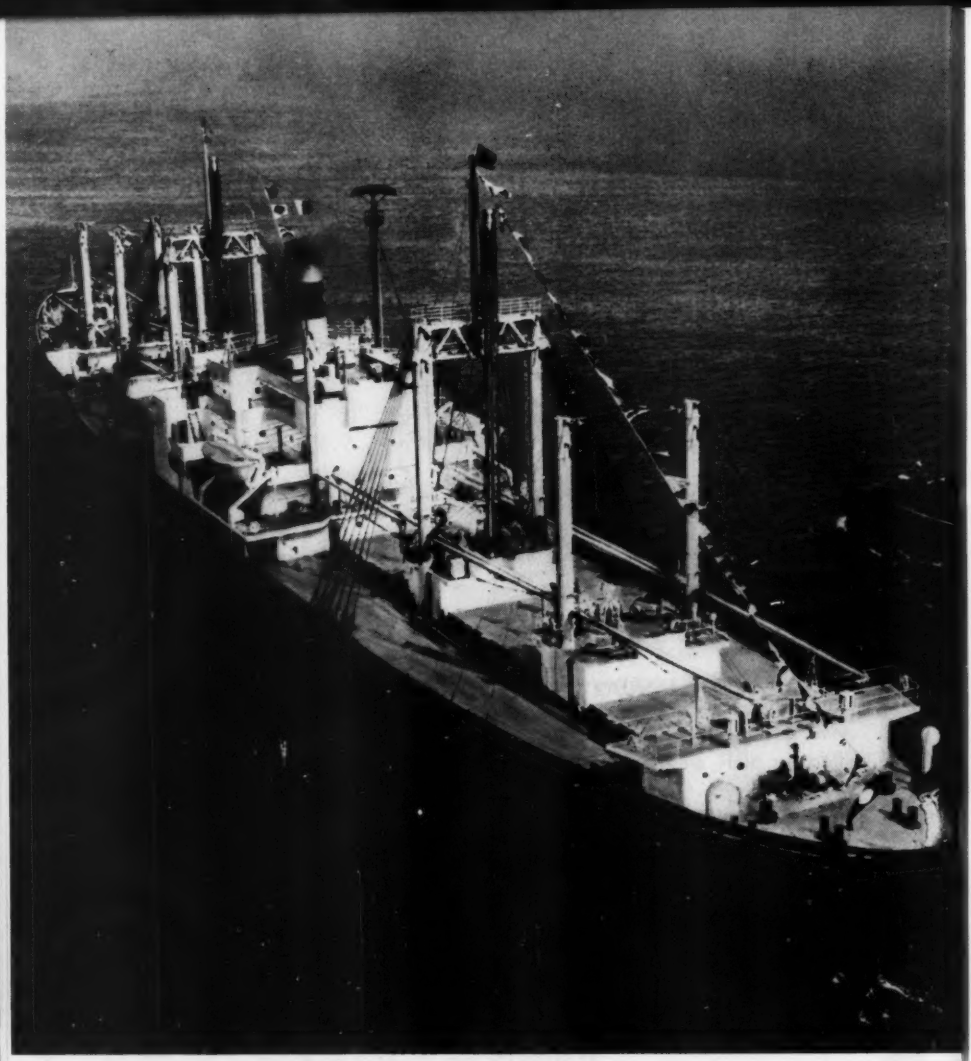

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JOURNAL
OF
THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

VOL. 66. MAY 1954. No. 2

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SECRETARY'S NOTES

THE 1954 BANQUET

The Society's annual banquet was served on 30 April 1954 at the Hotel Statler in Washington, D.C. The attendance was the highest of all time, slightly higher than in 1953 and getting very close to the maximum capacity which is now available in Washington.

The meeting was presided over by Rear Admiral E. W. Sylvester, U.S.N., President of the Society. Mr. William E. Blewett, President of the Newport News Shipbuilding and Drydock Company officiated as toastmaster.

The principal address, entitled "The Education of Engineers" was delivered by Vice Admiral E. L. Cochrane, USN, Retired, Vice-president of the Massachusetts Institute of Technology. Unless printing difficulties prevent, a copy of Admiral Cochrane's talk will be found on page 285 of this issue of the JOURNAL.

The concensus of those who participated in the meeting marks it another outstanding success.

REAR ADMIRAL FREDERIC R. FURTH
U. S. Navy, Chief of Naval Research
President of the Society

FUTURE BANQUETS

For those who are interested in long range planning, we announce that the facilities of the Statler Hotel have been reserved for:

29 April 1955 and
27 April 1956

COUNCIL MEETING

A meeting of the Council was held on 5 April 1954. Aside from the consideration of routine business, the following matters of importance were disposed of:

Office of President

Admiral Sylvester announced that he would be detached from his present billet in the Bureau of Ships and would be leaving Washington in May. Under the by-laws it became necessary for the Council to name a successor. Accordingly the Council appointed Rear Admiral Frederick R. Furth, USN, Chief of Naval Research to serve for the remainder of 1954. Admiral Furth's appointment is effective on the date on which Admiral Sylvester departs from Washington.

Elevation of Admiral Furth to the Presidency created a vacancy on the Council. Captain H. M. Heiser, U.S.N. was appointed to this vacancy for the remainder of the term which expires on 31 December 1954.

Junior Membership

A committee which had been appointed previously, reported on a proposition to create a Junior Membership. The Committee recommended such a membership to be offered to students at certain schools during their senior years. The Junior Membership would cost one-half regular membership ($3.75) per year and could be retained until 1 July of the year following graduation.

The proposition which will require a change in the by-laws, will now lay on the table for consideration at the annual meeting in October. If it is approved at the annual meeting, a proposed amendment to the by-laws will be included on the 1955 ballot for voting by all members.

PRINTING OF THE JOURNAL

The present issue of the JOURNAL is the 262nd continuous quarterly publication since 1888. Every one of the first 261 issues was printed by the firm of R. Beresford, a name with which most members are certainly familiar. This issue is the first *ever* to be printed by any one else.

R. Beresford, Printer was operated by its founder Mr. Robert Beresford until his death in 1919. He was succeeded by his daughter, Miss Elizabeth Beresford who had learned the craft under her father's tutelage. Every Secretary-Treasurer of the Society in the last 35 years has become accustomed to the gracious and willing assistance of Miss Beresford on every feature of the task of turning out a satisfactory issue of the JOURNAL. Through two and a half wars Miss Beresford has unfailingly met every problem of labor shortage, paper limitations, metals availability and mailing restrictions and in the face of these difficulties has begun delivery of each issue when it was due.

The members and other readers can each render judgement on the quality of the Beresford product which has never been criticized as far as this Secretary-Treasurer is aware. Only from this position, however, can the true value of Miss Beresford's contribution to the success of the Society be appraised. It is more than an opinion, it is a statement of positive knowledge, that Miss Beresford has been an essential member of the ASNE staff and that she is entitled to the highest possible credit. She has this, to an extent, in the esteem, respect and appreciation of all Secretary-Treasurers.

Under the circumstances, it was inevitable that some day a change would have to be made. This has been done for this issue which has been printed by The Benson Printing Co., of Nashville, Tennessee. This firm has undertaken to continue the Beresford quality. Again the matter is left to the judgment of the reader.

ENGINEERING DUTY OFFICERS

The following excerpt is taken from a letter which Captain R. B. Madden received from Commander J. A. Obermeyer, U.S.N. It adds one more fact to the history which the Society has been recording and to Captain Madden's article which was published in the February 1954 issue.

"I thought you might be interested in some details omitted from your article but which have a bearing on the personnel history involved. You properly state on page 27 of the JOURNAL that the first group of officers to take the "congineer" course were from the Naval Academy Class of 1937; however, a number of members of the Class of 1937 and three members of the Class of 1936, who entered M.I.T. in the spring of 1939, took the last course in naval construction but never became officially members of the Construction Corps.

"As you will recall, it had been the practice to issue commissions in the Construction Corps when the officers were promoted to Lieutenant Junior Grade at the completion of three years of commissioned service. Since this particular group was at Tech during the period of transition concluded by the official establishment of the Bureau of Ships in June 1940, and the amalgamation of the Construction Corps in the same month, no commissions in the Construction Corps were ever issued for them.

"However, since these officers had received the same training as previous members of the Construction Corps and had not taken a "congineer" course, they requested and were designated as Engineering Duty Only Officers (Ship and Hull Construction), which was the same designation given to ex-constructors. Engineering Duty Officers with a "c" designator.

"A list of the officers involved is as follows:

Commander F. G. Springer 1936
Commander W. N. Price 1936
Commander E. J. Hoffman 1936
Commander J. A. Obermeyer 1937
Commander E. A. Grantham 1937
Commander R. E. Ball 1937
Commander J. M. Ballinger 1937
Commander P. B. Moore 1937
Commander W. D. Brinckloe, Jr. 1937
Commander F. F. Menefee 1937
Commander F. M. Lansdowne 1937
Commander H. B. Reece 1937

"You properly omit these people from the list appended to your article of the original Bureau of Ships E.D.O. group since they had not been commissioned as constructors, but they do form a special group which does not fit into your classification of the types of officers now constituting the Engineering Duty Officer group. In other words, they are not former naval constructors nor are they "congineers'."

"In addition, I would like to call your attention to the fact that commanders I. J. Frankel, J. J. Stillwell, J. B. Shirley, and J. F. Ellis, who are listed as former naval constructors, because they were commissioned as Ensigns in the Construction Corps prior to the beginning of their course at M.I.T., actually pursued the congineer course while at Tech and are now designated as congineers. In addition, it is interesting to note that Captains Mumma and Trescott carry congineer designations although neither, of course, took the congineer course at Tech. I am sure you are aware of the circumstances leading to their designations as congineers."

We also reprint below an article which was published in the *North American Review* 36 years ago. It was written by Rear Admiral Henry Williams, U.S.N. Retired who was then a Lieutenant Commander in the Construction Corps. Although not published until 1918, the paper was prepared in 1910. Rear Admiral Williams' distinguished career included a term as President of the Society in 1940.

"NORTH AMERICAN REVIEW

November 1918

A NAVAL CONTROVERSY

By Henry Williams, U.S.N.

The recent order of the Secretary of the Navy authorizing officers of the Staff Corps of the Navy to use the titles of their rank again brings into prominence a long standing controversy. This controversy between the Line and the Staff Corps of the Navy is nearly as old as the Navy itself. It has been the subject of more discussion, in and out of the service, than any other naval topic; and for many years invariably was brought into prominence, whenever legislation affecting the Navy's personnel was under consideration. It has been waged through the desire of the members of the several Staff Corps to improve their status in the service as regards rank and official position, and their wish to destroy the caste distinction which has existed in the Navy, placing officers of the Line on a higher plane officially than officers of the Staff. Though the question is not entirely one of military rank or titles, staff officers have sought both rank and titles with the idea that such an acquisition would result in an improved position and status for themselves.

The Corps of Surgeons of the Navy, the oldest branch of the Staff Corps, was the first to make an effort to improve its position and status in the service. As early as 1816 a petition was addressed to the Navy Department by a number of surgeons of the Navy requesting definite rank in the service. This petition met with the approval of a number of captains of the Navy, who wrote expressing approbation of the proposed change and hope for favorable action. The Board of Navy Commissioners approved the request, stating that it seemed just that Navy surgeons should be put on the same footing regarding rank, pay, and emoluments as those of the Army. Due to opposition of line officers, however, no definite steps were taken to this end, though several of the various Secretaries of the Navy submitted to Congress recommendation that it should provide by law for the desired rank, etc., for the surgeons.

As late as 1841, staff officers of the Navy in the various branches, though nominally commissioned officers, actually had few of the rights and prerogatives as such. Surgeons, pursers, and chief engineers messed in the ward-room, used the starboard gangway, and had the same share as a lieutenant in the prize-money; assistant surgeons and assistant engineers messed in the steerage and used the port gangway. Codes of Navy Regulations proposed in 1833, 1841, and 1843 provided for "an assimilated rank" for "civil officers" of the Navy. These codes never received the necessary approval of Congress, and, consequently, did not become effective. The proposed code of 1841, referred to, provided that "the civil officers of the Navy shall have assimilated rank with the sea officers of the Navy as follows: Surgeons, pursers, chaplains, and secretaries with lieutenants of the Navy; passed assistant surgeons with masters; other assistant surgeons and professors of mathematics with passed midshipmen, and clerks with midshipmen." Masters and passed midshipmen were warrant officers.

The custom of the service at this time required that surgeons and other civil officers should give way to the lieutenants upon entering and leaving boats, in processions and elsewhere. No civil officers sat on courts-martial, wore epaulettes on their uniforms, nor had any privileges of "assimilated rank" other than as accorded by the customs of the service and by the courtesy of their messmates, the lieutenants.

The civil officers, particularly the surgeons, were greatly dissatisfied with the conditions under which they served and with their anomalous position on shipboard, and repeated efforts were made to have an improved status accorded them.

This question of rank for civil officers was brought repeatedly before the public and incidentally before the committees of Congress. The pretensions of the staff officers were opposed successfully, however, by the line officers, who were sufficiently influential to block any legislation granting the desired rank; the staff officers, on their side, were by no means united as to what they wished and what the various branches should receive.

In August, 1846, Secretary Bancroft, despairing of obtaining a settlement of the matter by Congress, with the approval of the President, and in accordance with an opinion of the Attorney-General, who held hat such action would be legal, issued an order that stirred profoundly the naval organization, conferring, as it did, on the surgeons the long-desired rank, and making them, according to the number of years service, rank with commanders and lieutenants. The order provided, however, that commanding and executive officers when on duty should take precedence over all medical officers. The provisions of this order were soon extended to the pursers.

The Line refused to accept gracefully the defeat that Mr. Bancroft's order represented, and staff officers were encouraged by its terms to overstep the bounds. A state of insubordination in the Navy ensued and line officers had just ground for the charge, brought by them, that the discipline of the service had suffered as a result of granting rank to surgeons and pursers; but, unfortunately, the charge that they themselves had brought about and were responsible for such conditions was more or less just. Several petitions were drawn, addressed to the Secretary of the Navy or to Congress, and signed by numbers of line officers, asking to have the obnoxious order rescinded. A group of about sixty line officers went so far as to assemble in Washington, for the purpose of procuring the revocation of the order. They addressed to Congress and the Secretary of the Navy a formal protest against its enforcement on the ground of illegality of the executive action in issuing it. One line officer wrote that he held his rank dearer than life itselt and threatened to cleave to the chin with his cutlass any purser of the Navy who might presume to sign an official report above him.

In spite, however, of protests from the line officers, some of which then must have appeared, as they do now, most ridiculous and undignified, the staff officers gained their point, and the orders of 1846 and 1847 were upheld, later to be legalized and extended by act of Congress. Engineers in their turn were granted rank in accordance with the length of their service, by act of Congress of March 3, 1859.

In 1860, in the United States Navy, there were but three grades of commissioned officers in the Line, those of captain, commander, and lieutenant, the title of commodore being one of courtesy only. Masters were warrant officers, not in the line of promotion. Under the provisions of the naval appropriation act of 1860, pursers were designated as paymasters. By act of July 16, 1862, Congress created the additional grades in the Line of rear-admiral, commodore, lieutenant-commander, and ensign, the Staff Corps not, however, being included in this legislation. In March, 1863, Secretary Welles, following the example of his predecessors, and in accordance with an opinion of the Attorney-General holding such procedure to be legal, issued an order defining the Staff of the Navy, and specifying what the relative rank of each grade should be. Besides surgeons, paymasters, and engineers, others were mentioned as staff officers, and given relative rank in accordance with the length of their service.

A line writer of this period characterized the Welles order as stabbing at the military honor and professional life of line officers, then nearly all in command before the enemy. He stated that if any of the line officers had committed every crime in the calendar they could not have been sentenced by court-martial to undergo such a loss of rank as inflicted by it.

This order, though resented bitterly by the line officers, continued in force throughout the Civil War, but was revoked by the Navy Department in another order signed by Secretary Borie, on April 1, 1869, Vice-Admiral Porter, an unrelenting foe of staff rank, having then to a large degree the direction of the Navy Department.

It was stated by a member of Congress, in 1894, that Admiral Porter's order was read at general muster on all naval vessels and the staff officers required, then and there, in the presence of other officers and crew, to remove the marks of their rank.

In effect, the order acted to reduce the rank of a number of staff officers, and to take away the designation "Staff Officers" from all except surgeons, paymasters, and engineers, who retained only the rank conferred on them by law of Congress. The *Navy Register* issued January, 1869, listed all "civil officers" with military rank, some of them with that of captain; this was changed in the *Register* for July, 1869, which showed only surgeons, paymasters, and engineers with rank, the highest being that of commander.

It is probable that this order of Secretary Borie was indirectly the cause of the triumph the staff officers were destined soon to achieve, for they were so successful in presenting to Congress their cause, and in stating the injustice that had been done them, that the Naval

Appropriation Act, passed March 3, 1871, contained provisions fixing definitely the status of all staff officers, the principle of relative rank and precedence, and gave the staff officers the six years' constructive service in determining such relative rank. This act established the various grades of the Staff Corps as they now exist, and in general its provisions must have been more liberal than was hoped for by even the friends of the staff officers.

It is probable that at this juncture, subsequent to 1871, the "controversy" was more bitter than it had been at any previous time. At the close of the Civil War it was said to have been responsible for the failure to confer on officers of the Navy, as had been done so generously for those of the Army, the brevet rank as a recognition of service. Rather than concede even brevet rank to staff officers, the Line was willing to forego the honor for itself. The Staff smarted under the injustice that they felt they had received at the hands of the Line, and the bitterness of the fight they had just waged before Congress still rankled. Admiral Porter, in a letter addressed to the Secretary of the Navy, said that honorary rank had been conceded for the purpose of establishing the status of civil officers on board ship, and that they were favored with the compliment of rank to identify them with their surroundings and to give property to their presence.

The engineers, from the close of the Civil War, were the most aggressive of the Staff Corps in the fight for titles and rank. The profession of engineers was looked down on by the line officers, and there is no doubt that they submitted their brother officers of the engineer branch to many unnecessary humilitations. Owing to rapid promotion, consequent on the reorganization of the Navy at the close of the Civil War, there were many young line officers in the higher grades. The older staff officers found this extremely irksome and disagreeable. Some of them who had been instructors at the Naval Academy went to sea at the close of their details, to find themselves junior in rank to their pupils of a short time before.

With the establishing in 1871 of a course for Cadet Engineers at the Naval Academy, the position of the naval engineers in the service was somewhat improved. This was due not only to the fact that a better class of men were obtained, but also because, through their association at the Naval Academy with the midshipmen, the latter were somewhat more kindly disposed to them later when they became engineer officers; and through the knowledge of service customs and traditions gained at the Academy, which gave the young engineer officers more confidence when they entered upon their duties afloat. In 1882 Cadet Engineers were merged with the Cadet Midshipmen, all becoming Naval Cadets. The selection of those to be assigned, upon graduation, was not made until the end of three years at the Naval Academy. It was claimed, however, that at the Naval Academy many line officers influenced the minds of cadets against

the Engineer Corps, thus preventing some who had mechanical preferences and displayed high scholarship, from joining that division, and it was claimed also that many cadets whose class standing made them undersirable recruits for the Line were forced to become engineers. Frequent efforts were made in the ensuing years to obtain personnel legislation for the Navy, and a number of bills were introduced before Congress, only to meet with failure through the opposing interests developed by the controversy.

In 1894 a joint commission of Congress was appointed to investigate and consider the entire subject of rank, pay, and all matters relating to the personnel of the Navy. The bill, recommended by the Navy Department to the favorable consideration of the commission, provided only for the reorganization of the Line, and ignored the Staff Corps' claims to legislation for improving their status, and for absolute rank in place of relative. The report of the hearings before this commission shows the same bitterness between the Line and the Staff over the question of rank and titles as previously had existed for over half a century. The engineers were more insistent in this regard than were the other branches of the Staff Corps, through the surgeons and the paymasters both complained of the unsatisfactory conditions existing as to their status.

The bill advanced by the engineers and pushed vigorously by them, contained so many provisions unacceptable to the Line, and was opposed so bitterly by it that the whole proposed scheme of personnel legislation failed of passage by Congress.

In 1898, conditions as regarded the personnel of the Line had become extremely bad, the Civil War "hump" had caused such a stagnation of promotion that officers served ten and more years as ensign, also there were lieutenants in the Navy fifty years old. The strength developed by the engineers in their fight before Congress in 1894 was such as to cause line officers to realize that no legislation affording them relief, without provision for absolute rank for the engineers, could be obtained. The other branches of the Staff Corps were not regarded as being so formidable, though it was realized that their support would be desirable. The ever-present question of staff rank was certain to be brought forward, and it was concluded to give not only consideration to the engineers, but also to the claims for absolute rank of other staff officers. The famous Personnel Bill, passed by Congress in 1899, provided for amalgamating the Engineer Corps with the Line and, by the simple expedient of making line officers of them, conferring on the engineers the long-sought-for military rank and titles. To the officers of all the other branches of the Staff Corps of the Navy the Bill accorded "rank" instead of the "relative rank," which they held under the provisions of the act of 1871. The committee in its report transmitting the Personnel Bill to Congress stated that the question of rank had occasioned frequent dissatisfaction in the past, and that, after investigation, it had come to the conclusion that there was no reason why there should be any distinc-

tion in the matter of rank between staff officers and line officers, and that the Staff should be commissioned with actual rank, the same as in the Line and in the Army. However, they provided that because staff officers were commissioned with actual rank, they should not as a result have the right to command. Further, it was stated: "The committee believes that they should still retain the titles which they now have, description of their duties and their Corps, but think their status in the Navy in the matter of rank should be thus firmly established."

The Line and Staff controversy which, in 1899, thus had been settled temporarily was destined not long to remain quiescent. Personnel legislation was required to relieve conditions in the Line. In a special message to Congress, on December 17, 1906, the President invited attention to the urgent necessity for such legislation as would cause line officers of the Navy to reach the grade of captain and rear-admiral at less advanced ages than was then the average, and that would give the officers more experience and training in the important duties of those grades. The President forwarded a draft of a proposed bill as recommended by a personnel board. This measure included no provision for the Staff Corps, and in reference to this omission the Secretary of the Navy stated in his annual report for 1906, that he refrained from any recommendation relative to the portion of the report of the personnel board dealing with the Staff Corps "because it is impossible to say that it has, in the main, received the approval of the officers most directly affected, and I am not prepared to advise the embodiment in legislation of any plan which will not finally and once for all end the regrettable differences existing between the Staff Corps and the Line."

The dispute between the Line and the Staff thus in 1906 again reached an acute stage and was brought to the notice of the public because of the failure to accede to the wishes of the Staff that there be included in the proposed measure provisions relating to the personnel of the Staff, especially for military titles for its officers. Many of the line partisans did not hesitate to accuse the staff officers of maliciously exerting their influence in opposition to the passage of the Personnel Bill, through spite at the refusal of the Line to accede to their wishes in the matter of military titles. Editorials published in the New York *Herald*, favoring the measure, stated that it was opposed by some officers of the Staff Corps, who combined secretly to obstruct or kill the passage of the bill, not because its provisions affected them, but because of its failure "to accord these important and capable officials" the Line titles of admiral, captain, and so down the hierarchy of the seas. It was stated further that this opposition was arrayed with such influence and persistency as to threaten the defeat of the Personnel Bill, which was regarded as a disaster for which a day of reckoning awaited. These statements as to the activities of the Staff, in all probability, were greatly exaggerated, but the incident serves to show clearly the fact of the continued existence at that time of bitter feeling.

The Personnel Bill failed of passage, whether due to the opposition of the staff officers, lack of their support, or to other causes, would be impossible to determine, but the incident served again to demonstrate the difficulty, if not impossibility, of obtaining naval personnel legislation which lacked the support of any branch of the service. The normal difficulties attending the passage by Congress of any naval measure are so great, that any opposition, or even lack of support, is sufficient usually to cause its defeat. The question of titles and the right of staff officers to exercise military command under certain circumstances undoubtedly will be brought up in any discussion before Congress of naval personnel matters.

During the term of Secretary Meyer circumstances affecting administration of the business of the Navy Department and the Navy Yards again brought into evidence the feeling between the Line and the Staff. The Secretary, probably having in mind the amalgamation of the engineers with the Line and the consequent elimination of that portion of the controversy, sent to Congress a draft of a measure providing for general amalgamation with the Line of all Staff officers except the Medical Corps. The House Naval Committee conducted extensive hearings on this proposal, and a number of officers were heard or requested to submit statements as to their views. These officers represented all corps and all grades, and the report of the hearings fills a large volume. While the proposed amalgamation had comparatively few advocates, many of the Line officers took occasion to discredit the Staff officers' desire for military title, and the staff officers on their side advanced strong arguments upholding their pretensions. Considerable feeling thus was shown to exist at that time, on both sides of the controversy. While, since then no circumstances have occurred to bring out again a public expression of the sentiments and feeling, without doubt they existed as strongly as ever. It is, therefore, to be regarded as extremely fortunate that the recent order of Secretary Daniels, which should eliminate for all time this controversy, came at a time when the best efforts of everyone concerned are required to uphold American arms on the sea. In war time there is no room in the naval service for disputes so adversely affecting the efficiency of the service."

SOCIETY AWARDS

The Admiral Brand Award

As a continuing memorial to her late husband, Mrs. Charles L. Brand has provided for an annual award of a year's subscription of the JOURNAL to be made to the officer student standing highest in the graduating class in Course XIII-A, Naval Construction and Engineering at the Massachusetts Institute of Technology. The first award will be made this year.

Admiral Brand needs no introduction to the Society of Naval Engineers. He served as President in 1944 while, as an Assistant Chief of the Bureau of Ships, he was planning and supervising the most magnificent naval ship construction program in the world's history. Those who, like the present Secretary-Treasurer, had the privilege

of serving *with* (and not *under*) Charlie Brand know what a real pleasure this experience was. The award is not necessary to keep him alive in the memory of those who knew him but may help to spread his benign personal and technical influence among oncoming Naval Engineers.

The Carl J. Lamb Award

Captain Carl J. Lamb, U.S.N.R. has for a long time been one of the Society's staunchest supporters. He has exhibited this by recruiting members, by submitting articles and by encouraging others to submit papers. His latest method of support was to offer an award of a membership in the Society to the graduating senior in the Naval R.O.T.C. at Rice Institute, Houston, Texas who stands first in mechanical engineering and who accepts a Naval Reserve commission. Captain Lamb is continuing this award in 1954.

SOCIETY MEMBERS HONORED

Mr. George W. Codrington

"George W. Codrington was honored for his long service and active leadership in the National Assn. of Engine and Boat Manufacturers at a testimonial dinner held in New York early in December which was tendered Codrington by the members of the Association's Executive Committee. Mr. Codrington, who retired as president last January after serving in that capacity since 1943, was presented with a silver tray with the signatures of Executive Committee members who had served under him."

Vice-Admiral Edward L. Cochrane, U.S.N. Retired

"The appointment of Dean Edward L. Cochrane as Vice President for Industrial and Governmental Relations at the Massachusetts Institute of Technology was announced last night by Dr. James R. Killian, Jr., President of the Institute. The appointment becomes effective April 1.

In the new post of Vice President for Industrial and Governmental Relations, Vice President Cochrane, who has been Dean of Engineering since 1952, will be concerned with the whole range of the Institute's responsibilities to industry and government. He will serve to coordinate and to give administrative support to the special research and advisory activities at the Institute undertaken for industry and government, both national and local, and he will assist the President in discharging the executive responsibilities for this program. He will be a member of the Institute's Corporation."

SAINT OF THE LITTLE SHIPS

Mr. Warren T. Johnson, one of the Society's very active members and an able and helpful assistant, without portfolio, to the Secretary-Treasurer has unearthed the following article. It was published in the February 1954 issue of the British periodical "Motor Boat and Yachting." It is our opinion that this early naval constructor should be made known to members of the Society. Therefore, we reprint the article in full.

"SAINT OF THE LITTLE SHIPS

By Owen Anthony

Motorists have their St. Christopher, musicians St. Cecilia, even dentists can call for aid on St. Philomena, but we of the little ships have no patron. May I introduce a worthy candidate-St. Brendan, Bishop of Clonfert, born in Tralee, Kerry, Ireland, in the fifth century? Hagiologies listing saints' names usually add their salient attribute. Our saint is described as the Navigator. It may come as a surprise that at such an early date navigation should have been known, but after a short review of his life it will become clear.

Brendan, cradled by the side of the wild Atlantic fostered by the fisher folk, for his toy the tricky curragh, and his playground the rocky West Ireland littoral, grew to manhood. After attending the first boys' school managed by a woman, St. Ita's, he came under the tutelage of Bishop Erc, a convert to Christianity. This good man was, before conversion, an Arch Druid. The essence of the doctrine of Druidism founded on the teachings of Pythagoras makes movements of the heavenly bodies a special study. Geometry, higher mathematics and navigation were, so to speak, ordinary school subjects. Brendan, being a son of the sea, took a deal of interest in the last, and was determined to become a widely travelled missionary.

On his ordination to priesthood he returned to his native Tralee where he founded his own small monastery. Then, as always, he entertained the possibility of undiscovered land far out in the Atlantic, west of his own coast. Accident gave stimulus to this belief, and his determination to seek it. One of his monks, Fionn-Barr-he incidentally founded the city of Cork-met a fellow monk in a hermitage who, fleeing from the wrath of his superiors, took a large curragh and with a few companions made out to sea. After eight weeks' sailing they came in sight of a beautiful land set in a tropical sea, and covered to the shore with lovely flowers. The smell of spices wafted to them, delighting their senses.

The tale confirmed Brendan's belief and he started to lay down the keel of a large-size curragh and, helped by his fellow monks, began to build. Fortunately for us his chronicler gives precise information of its construction. The gunwale and the ribs were of willow, the laths forming the main skeleton, of wicker; and covering the hull thus formed were three oak-tanned hides arranged so as to form two airtight chambers. The joints were sealed with holly resin and the craft was finally sealed and caulked with tar. Quantities of butter were shipped to be liberally applied to the hull to render it watertight, and two extra skins were taken for repairs. The sail, triangular lug type, was made of strips of rubbed animal pelts. For preference, wild animals were used for this as they were supposed to retain their pliancy in salt water and were easy to reef and stow. The mast was carried unshipped and when needed it was stepped through a hole in the forward thwart and so to a mast shoe in the bottom.

The galley arrangements consisted of a brazier, beautifully wrought in metal. Some examples exist today and remain the only method of cooking used by the West Coast fishermen. In it is carried charcoal or smouldering turf, both substances being well known at

an early date. Resembling a shallow metal dish, it was slung between the thwarts by metal bars bridging from one gunwale to the other, thus protecting the skin. Water was carried in skins, and what better method could be employed in such a craft, fitting easily into the contours of the hull?

The staple food consisted of dried fish, grain, root crops and edible dry moss, carrigean—a substance now on the market and which forms a jelly when mixed with water, it is rich in iodine and vitamin C. Another plant shipped was a kind of sea holly, erygium, a powerful restorative and anti-scorbutic. It is of interest, that this simple necessity known to the ancient herbalists, should have been forgotten until the nineteenth century when it was revived by offering lime juice to the somewhat scornful gum-rotted sailor who scathingly described his ship as a "lime-juicer." It is not recorded that they carried additional clothing. They shipped the typical sword-shaped oars normally used in this type of craft.

IRELAND TO ICELAND

Brendan's gentle art of crew picking could to this day be copied by anybody intending an Atlantic crossing in a small vessel. A few only were monks like himself. The remainder combined the art of seamanship with that of artificer and general handy man in any tough situation. Last, but not least, he took Crosan, a retired king's jester. This, at first flush seemed odd, but how often has the recent war taught the commander the value in desperate circumstances of the cheerful little man, not a very good soldier, but a wizard on the mouth organ. Brendan was no mean judge of this man's use in the desperate hardships he knew his crew would suffer when the lack of food, monotony, frayed nerves and fear of death would wear down the morale of the stoutest.

Setting out amid the lamentations of his friends, who thought they would never see him again, Brendan and his crew stood out to sea, and with fatalism unworthy of a seaman, and less of the good theologian he undoubtedly was, hoisted his sail and let God and the winds blow him where they listed.

With many vicissitudes, blown by the wind's caprice, his course was mainly northwards when, none too soon, his supplies running low, he sighted the high cliffs of the sland of St. Kilda. His name is still remembered there to this day, for the fishermen in moments of extreme danger call, "Branuilt, Branuilt," a derivation of his name. Next they were wafted to the Faroes where they took advantage of the "sheep as big as calves." Legend is supposed to describe them as native to those parts. The word Farr being Danish for sheep, lends some tincture of truth to the idea. A church, ruined and shell-marked, built in his honour by Bishop Theutonicus in 1420, still bears the name of Brendansvik. A round tower typical of those in existence today in Ireland, bears testimony to the occupation by ancient Christian missionaries of the Island of Stremoe.

Landing on the Island of Noss in the Shetlands they, according to their chronicler, "soaked the salt out of their skins" in the clear waters of the river. After terrific physical sufferings they eventually made the shores of Iceland, where, much to their surprise, they were met by a fellow monk who had lived on the shores in hermitage for 30 years. After rest and recuperation, this good man pointed out to Brendan the folly of his sailing, and the futility of his voyaging, and advised him to return home to his native Ireland. He set out immediately, and this time with true navigational skill made the landfall without difficulty.

His next voyage was better planned. This time he built himself a ship able to withstand the rigours of the Atlantic winter, and offer shelter for his crew and cover for his stores. The exact structure has been given to us. She was made of stout oak, had a deck supported by wooden standchions, and she was tar-caulked. A lot of smithy work, iron rivets, not to forget an iron anchor, went into her making. Woven materials replaced the primitive hide sails. She carried no oars or sweeps and boasted of a crew of 60.

After some weeks they had fair winds and their course was mainly west. They were eventually in sight of land which, by their own description, could only have been the cost of Newfoundland, for nearing the coast they found it surrounded by glass islands of most wonderful beauty. These were obviously icebergs, unknown to these western men.

Turning south they eventually reached the coast of America where they landed on the shores of Florida, somewhere near Miami. To Brendan's chagrin he found missioners already established there. This brings up the query as to who did discover America. Ample evidence points to the conclusion that it was not Columbus.

Columbus was educated at the University of Pavia, where he learned most of the theory of navigation. The university was founded by the Irish monk Dungal, who brought with him into his exile many valuable Irish records, including the accounts of Brendan's voyaging. Columbus had free access to these and he eventually found them of extreme interest. He visited Galway, and there, on the last landfall of his famous voyage, collected all the information he could, taking with him many men with Irish names. These can be seen on the roster of crew of his "Santa Maria" still displayed in the Spanish national archives.

There are, perhaps, some signs of America's discovery by the Irish, though few pieces of evidence remain, but there do exist some relics of early Norse occupation, to quote some-the Deighton writing stone, an armoured skelton found in the Cat Island, one of the Bahamas groups, and a similar one discovered near Fall, Massachusetts. In Newport, Rhode Island, stands the oldest building in the U.S.A. It is a Norse mill or some such ancient structure. The Norse landing preceded that of Columbus by 500 years."

FLUORINATED HYDROCARBON REFRIGERANTS

Attention is invited to a letter which is published under "Discussions."

INDUSTRIAL COLLEGE OF THE ARMED FORCES

The Commandant of the Industrial College of the Armed Forces has very positively recognized the American Society of Naval Engineers by extending to our membership the privilege of enrolling in the College's extension courses. This can best be described by permitting members to read Admiral Hague's letter to the Secretary-Treasurer. It is published below without the enclosures which are quite lengthy.

Correspondence in connection with these courses should be direct with the College and not through the Society.

"Dear Captain Hamilton:

Many members of the American Society of Naval Engineers have participated in the educational activities of the Industrial College of the Armed Forces. Many others may not realize that these opportunities are available to them. I believe that your membership would appreciate information concerning the extension courses of the Industrial College.

The Industrial College of the Armed Forces is at the highest level of the Department of Defense educational system. The Extension Courses Division, as well as the resident course of the College, is dedicated to the education of selected military and civilian students in the general field of national resources— human, material, and economic—and their coordination for the security of the nation. Joint logistic planning and its relationship to joint strategic and national planning is also studied. World areas and their economic potential as allies or enemies of the United States are brought into clear focus.

The Extension Courses Division of the College consists of two branches—the Civilian-Reserve Instruction Branch and the Correspondence Study Branch.

The Civilian-Reserve Instruction Branch conducts National Resources Conferences (old title "Field Economic Mobilization Course") in sixteen different cities throughout the United States annually. During each conference, of two weeks duration, an objective study is conducted in broad terms of the economy and resources of the United States and the free world, and the limitations imposed thereby on national aims and objectives. The economies of the other nations of the free world and of the Iron Curtain countries are also considered. I cannot emphasize too strongly that the facts and factors considered by the conferences are of current importance and are necessary for an intelligent grasp of the very complex and difficult problems facing the country today.

The presentations consist of lectures followed by discussions. Instruction is given by a six man faculty team to reserve officers of the Army, Navy, Air Force, Marine Corps, and National Guard as part of their education. Civilian leaders in the fields of industry, education, science, labor, and civic life are invited to participate along with these officers.

Since the founding of this educational activity in January 1948, instruction has been given over ninety times in industrial centers throughout the country, with more than 22,000 individuals participating. In the enclosed prospectus you will note that there are only four cities remaining for conferences in this academic year, namely, Pasadena, California, 5-16 April 1954; Pittsburgh, Pennsylvania, 5-16 April 1954; Omaha, Nebraska, 26 April-7 May 1954; and Minneapolis, Minnesota, 3-14 May 1954. When our 1954- 1955 schedule is confirmed, I shall make it available to you.

I am enclosing in addition to the prospectus mentioned above, a copy of the brochure which includes the outlines of the lectures presented at the National Resources Conferences. From these you may get a fairly comprehensive understanding of all the subjects with which the conferences are concerned.

The Correspondence Study Course was started in September 1950, to meet the demand for more extended and detailed instruction in the field of economic coordination than that presented in the National Resources Conferences.

This course, designed to be completed in approximately one year, is conducted by the Correspondence Study Branch of the Industrial College of the Armed Forces. The College has prepared and published a text, "Emergency Management of the National Economy," together with other study materials paralleling those used in the resident course. There are self-administered examinations at the end of each of the five units of the course. 1,800 students are now enrolled, of which 500 are civilians. A current prospectus of this course is also enclosed.

I invite your attention to these two courses, stressing the fact that these studies cover present day and future planning. They embrace industrial coordination, economic, and civil defense problems which are now facing our country and which we must continue to face in this "age of peril."

The purpose of this letter is to inform you of these activities of the Industrial College of the Armed Forces and to extend to your membership a most cordial invitation to participate in either the National

Resources Conferences or the Correspondence Study Couse. Your members can enroll in these courses by writing to the Industrial College of the Armed Forces, c/o Extension Courses Division, Fort Lesley J. McNair, Washington 25, D.C.

Sincerely yours,
W. McL. HAGUE
Rear Admiral, USN
Commandant"

THE PENNSYLVANIA STATE COLLEGE

The practice of the Society in the past has been opposed to the publishing of notices of technical meetings, courses, etc. Principal reason for this is that the dates of publication of the JOURNAL rarely coincide with the dates to be announced. However, we have been advised of two short courses which should be of interest to some members and which will be held at the Pennsylvania State College about 1 month after this issue is received. We therefore, vary our practice by printing the following notice:

SHORT COURSES ON HIGH TEMPERATURE PROPERTIES AND MECHANICS OF CREEP

"A short course on High Temperature Properties of Materials will be held at the Pennsylvania State University between June 21 to June 25 inclusive. Following this course one on Mechanics of Creep will be conducted between June 28 and July 2. Authorities from industrial, governmental and educational institutions will give the lectures for both these courses. The programs are planned to give a broad coverage of high temperature properties of materials and mechanics of creep by including physical, metallurgical and design aspects of these subjects. For further information, please write Dr. Joseph Marin, Department of Engineering Mechanics, The Pennsylvania State University, State College, Pa."

ALUMINUM CENTENNIAL CONGRESS

An American Committee for the Centenary of the Industrial Production of Aluminum has been organized to cooperate with an Aluminum Centennial Congress, to be held in Paris June 14th to June 19th under the sponsorship of the President of the French Republic. Announcement of the Committee was made today by William P. Bittenbender, its Chairman.

The Aluminum Congress will mark the 100th anniversary of the development of industrial aluminum by the French scientist Henry Sainte-Claire Deville. The sessions in Paris, to be presided over by Professor Albert Portevin, of the French Academy of Sciences, will include a program of scientific papers from all over the world on the latest developments in aluminum metallurgy, the chemistry

of aluminum compounds, and on the technology and uses of the metal and its alloys. There will also be visits to laboratories and plants in Paris and in other parts of the country.

Along with the Congress there will be an exhibition on the Seine embankment in Paris, dealing with 100 years of development of the aluminum industry. The exhibit will be open to the public from June 10th to August 15th.

In his announcement, Mr. Bittenbender declared that the formation of the Committee was in conformity with President Eisenhower's recent recommendations on the expansion of foreign trade as important to U.S. and world economy. "American manufacturers, importers, importers and exporters," he said, "are glad to join in an event commemorating the development of an industry that has vastly extended industrial horizons and that has brought inestimable material progress to hundreds of millions of people in all parts of the world."

THE EDUCATION OF ENGINEERS

This was the principal address by Vice Admiral Edward L. Cochrane, U.S.N., Retired, a Vice President of the Massachusetts Institute of Technology, at the 1954 annual banquet of the Society.

Mr. Toastmaster, Mr. Secretary, President Sylvester, Distinguished Guests, and Fellow Members of the American Society of Naval Engineers—

That my subject tonight would unescapably appear to be a self-inspired commercial did not occur to me until long after our President had asked me to speak on it at this annual banquet. That subject might be more subtle, were I going to speak about beer or cigars, or perhaps tru-form brassieres. I assure you most earnestly, that *I* did *not* choose the subject. In fact, in the words of Cal Coolidge, I did not even choose to speak and had I not agreed to do so, come hell or high water, I would be inclined to undertake a bit of research at this point.

I have *always* been *curious* to *know* just how many of those, such as *yourselves*, who, for any reason, good or more probably bad, find themselves at a banquet and are confronted with a gloomy, after-dinner speaker, such as *myself*, would not prefer to forego the remote chance of mental uplift, in exchange for the certainty of good fellowship and good cheer in a more intimate gathering—in a smaller room no doubt where the tinkle of ice in glasses could be heard ringing sweetly above the voices.

As you know, educators are all hell for any kind of research and I would jump at this opportunity to do some scientific work on this project tonight were I not sure in advance that, *did* I ask how *many* of *you* wanted to cut the speech, the "ayes" would

be overwhelming. Such a result would relieve me personally no end, of course, but it would embarrass our president terribly and shatter a precedent, that *is* as a matter of fact, long overdue for shattering.

I am therefore resigned to my commitment and urge that you my dear listeners, stretch out a little farther and resign yourselves to the ordeal also.

As a matter of fact, I told Jimmy Hamilton that this was a silly subject for this banquet. Everybody here is supposed to be educated already and, certainly, if any of you aren't, you were resourceful enough to get in through the side door or the back door or perhaps through a second-story window.

But no matter how we got here tonight, you can put it down that you are lucky not to be going through a technical college today, because learning engineering is getting tougher year by year.

Fortunately, the boys are getting smarter and more able or maybe just because there are more of them it seems easier to pick able ones. But when you think of all that these young people have to learn, it takes your breath. To be sure they now give up some things that you and I had to do, particularly in practical work, and more especially in reading the painfully dry descriptions of how someone else had done a particular job in years gone by or how a particular machine was built or operated or a process run.

Sir Winston Churchill, as you may recall, told us when he was here back in 1949 that he had not *had* the benefit of a formal college education and that he had just had to pick up what he knew as he went along. Present-day boys seem to do the same thing in learning to use their hands. Hot-rods, radio sets, outboard motors or farm machinery come to them intuitively. When they get into one of the Armed Services ingenuity seems to become a sixth sense, the very means of survival in many cases.

Now, gentlemen, it has been aptly said that a political platform, like the platform on a trolley car, is something that you *get in on* and not something that you *ride on*. Similarly it might be said of a preacher's text or of the subject of a professor's lecture.

I had some very well-chosen words to use tonight, but I assure you that they, like every other collection of similarly chosen words were transcendingly dull. They were totally inadequate to my feelings at the moment; for they were written on the flimsy premise that the present status of the world, and of *this* country in particular, will not deteriorate in the ensuing decades.

Sitting here snugly as we are tonight, we all expect confidently that *that at least* will be true and in our hearts all of us hope that we shall soon return to the "old days" of peace, quiet, and no taxes.

I, too am an optimist by nature, but let us not kid ourselves. I can take kidding, I think, with anyone but by God, I hate to discover that I am kidding myself.

Gentlemen, there is nothing about which we of the Western Nations can be complacent today. The comfortable place that we had until twenty years ago has evaporated. We used to say that the United States had never lost a war. The holds of that proud ship have been bilged. She is making water. She was not sunk on the 38th parallel of Korea, but a treaty is yet to be signed.

Everywhere the Western Nations are retiring and new forces are rising to challenge our position. The Colonial empires have crumbled. Meanwhile our dependence on the rest of the world grows—and our vulnerability to the will of foreign lands grows as rapidly.

We are playing for high stakes in the modern weapons—we speak of "catastrophic retaliation." That is a bluffing game. It does not make sense. When you see our own youngsters beating each other into insensibility in a prize ring for fifty or a hundred bucks—the idea that nations, which are composed of men, and have all of man's frailties and few of his virtues, will be deterred from some action which they decide to be to their advantage or need, because some of their people will get hurt—is not sound.

I was encouraged to hear Dr. John A. Hannah, Assistant Secretary of Defense, voice yesterday afternoon what is to me, a wiser view—and that is—that we must keep ourselves so strong that any would-be aggressor will know that if they start something, they will get the hell knocked out of them as a result. That is not a direct quote from Dr. Hannah, of course, but it is clearly what he meant, and what I believe.

This is an objective far more easily stated than accomplished. It will be expensive in our money, in our time, and in our resources, and even more, it will be expensive in its effect upon the citizens of tomorrow.

They must be resigned to devoting much of their effort to designing and building instruments of defense and weapons of offense. Such work is not stimulating to ideals, not satisfying to one's ambition to enhance the enduring stores of knowledge or of esthetic worth, to making the world a happier place in which to live.

What does this mean to you and to me? Clearly since it was during our term as officers-of-the-deck that things got so fouled up we must leave no rocks uncharted, no shoals unmarked for these young people to whom you and I will turn over the responsibilities within a few short years.

They deserve, and we owe to them, the best that can be made available in schools and colleges. We owe them time to absorb the fund of knowledge that is available. We owe them patience, guidance, and encouragement. We owe them also an example of diligence, thrift and integrity—discipline if you will.

Young people, even as you and I, operate on Newton's first law of motion. We all tend to remain in a state of rest or of uniform motion in a straight line (often slow motion too) unless acted upon by an impressed force. In human beings, this force may be the urge to eat, but the greatest urge is the desire for respect from one's family or associates—to justify the confidence of those around us.

There was a time when engineers were content to follow science—perhaps occasionally to ignore. Those times are gone, today scientists and engineers work side by side with mutual advantage. The term "long-hairs" was used during the war, but I assure you that many pairs of calloused hands went with the "long-hairs" and still do. They know how to take off their coats and are doing it. Such teams are not interested in the question:

"Can we do it?"

but the critical one:

"What do you want done?"

They are not tied to tradition, to handbooks or descriptions of past effort. They will tackle and tackle successfully almost any job.

Yet seldom, I suspect, is insurance taken on such boys to protect the employer against losing them by other causes. We need to give thought to these young to keep up their morale, before they go into uniform, even more while they are in and again during the period of adjustment afterward.

In technical education today the astonishing transmutability of the various engineering professions and of the scientists which was established so clearly both here in the United States and in Europe during the period of World War II is very apparent.

The boundaries of the old professions are becoming less and less clear. The knowledge needed for competence in each of them is becoming more and more universal; the relations between them, more and more intimately interlocked. A fighter plane today is a jet engine around which an air frame has been wrapped. A few, very few, cubic feet are reserved for a pilot and the balance is filled with fuel and electronics. In fact, a large share of the fuel is usually carried in separate detachable wing-tip tanks. The best of most of the engineering professions contributed to such a product.

Ships and particularly men-of-war which are the pride and joy of most of us and the symbol under which we assemble here tonight are even more complex, if not as compact as a jet fighter. Every branch of engineering is called upon to make some contribution and all of the professions come in somewhere.

Boys and many men do not know just what they prefer to do, and surely do not know much in advance what fate may have in store for them. Because of this and because of the enormous importance of a firm foundation of science and mathematics, the trend in engineering education, is to keep the courses as broad as possible during the undergraduate years and to delay the selection of a specialty at least to preserve the possibility of a change in specialty wherever this is possible.

To be sure, most youngsters need the inspiration of a profession to spur them on. They, like all of us, yearn to do something, to be somebody, to gain the satisfaction of accomplishment. This yearning cannot be neglected. Educators call it motivation. While the word annoys me, it describes the stimulus that the embryo-engineer or scientist needs to carry him on toward future success.

The need for a solid base means that the bachelor of science in engineering is no longer ready to move at once from graduation to a responsible engineering assignment in an advanced field. He needs training to adapt him and sharpen him for the realities of the commercial world. He is fine timber with which to build, but he may not be surfaced four sides or molded exactly to your pattern.

Give him back to us for graduate work if he can qualify and he can be returned to you with as high a polish as the metal will take, and experienced in the most modern techniques available. He will still be a young man, and judgment improves with age and experience, but these youngsters season rapidly.

I referred to the growing fuzziness of the boundaries of the old professions. The professions are, of course, still vigorous and still furnish the line organization of administration in schools and in practice, but there is a growing need for a crossing horizontal function between the professions in area of common interest, such as

fluid dynamics, electronics, materials, acoustics, nuclear engineering, heat transfer, to mention but a few.

Acoustics, for example, involves physicists, electronic and electrical engineers, psychologists, physiologists, mechanical engineers, architects, and fluid dynamicists. How best to organize an academic laboratory in which such diverse professions work on a permanent basis is a problem yet to be solved.

The increasing speed at which man-made devices can operate today is outstripping man's own ability to direct them with continued accuracy. Psychologists and physiologists are needed in continuous consultation to keep man's part in new devices within the capabilities of human beings who must operate them. Servo-mechanisms can be developed to do automatically what man cannot do. Servos cannot reason, of course, but they can solve with lightning rapidity particular problems and can do so with the highest fidelity.

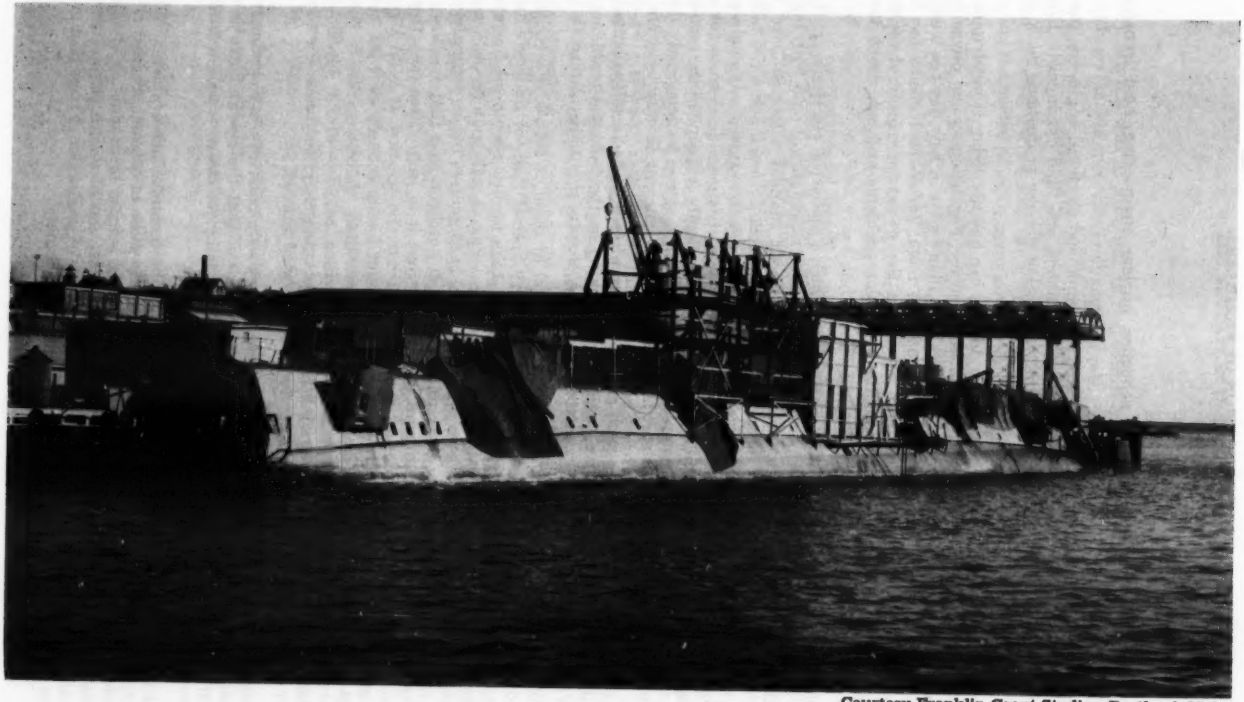
We have, for example, a big milling machine for which a numerical electronic control system has been built which will permit it to reproduce automatically and with half-thousandths fidelity elaborate machined parts without manual attention save to set the machine up and to start the process. We have recently machined a die block for the master connecting rod of a large radial air engine which requires only moderate hand finishing to be ready for service. I am advised that it is possible even to set up the programming for certain mathematical forms automatically with one of the modern digital computers. This is but a sample of the devices and, as can be imagined, there are innumerable problems of this sort associated with the current defense program.

It is my conviction that it is in such an atmosphere of intimate association between most advanced science, progressive engineering working on the technical problems of the day, that the engineers for the next two or three decades should be trained.

My views in this regard may appear to be critical of some of the Navy's training of its own engineers. The Naval Academy is a very special form of undergraduate college and one which handles its problem superbly. I am far less convinced, however, that the Navy is creating the best values in the men whom it selects as its uniformed engineers by training them in its own graduate school at Monterey, I want to emphasize that I refer only to the training of engineers there. It has been said that the Navy is training primarily operating engineers at Monterey but it is from these men that a good many of the Navy's own design engineers will later be selected. It is on a good many of these men that the Navy will have to depend for its contact with the commercial industries in a future emergency. I am confident, therefore, that a policy which would send uniformed engineers to the civilian colleges would pay double dividends for this country in preparing for a future emergency; readiness for which is after all the only excuse for maintaining the Armed Forces.

If aught that I have said conjures in your mind's eye a picture of a certain Institute of Technology in New England, I would have to admit that the resemblance is not accidental, but I have used it as an example only. It is by no means a unique unit of this country's system of technical education.

This country has prided itself over the years in its technical achievements. When the chips are down, however, one must admit that the score of original creation is not one-sided in our favor. We have risen to astounding heights in production. I repeat that my plea is for the development of a rising generation of young engineers who can maintain superiority of ideas as well as of quantity of production. I hope that many of these will devote themselves to ships—and ships' machinery.



Courtesy Franklin Grant Studios, Portland, Maine

U. S. S. NAUTILUS (SSN 571)—The world's first Atomic-powered ship, just after her launching.

ATOMIC POWER ON SHIPBOARD-LET'S BE PRACTICAL

HOLMES F. CROUCH
Lieutenant Commander, U. S. Coast Guard Reserve

THE AUTHOR

was a graduate of the U.S. Coast Guard Academy in 1940, Mr. Crouch spent 5 years on Coast Guard vessels at sea. Seven years of Coast Guard service were spent inspecting merchant vessel hulls, boilers, lifesaving equipment, etc., after which he resigned from the Coast Guard in early 1952. He spent one and a half years with a private contractor for the Atomic Energy Commission studying nuclear reactors for central-station power. He is now with an industrial advertising agency and is pursuing a graduate program at the University of California in Nuclear Engineering.

In June 1951, the keel was laid for the world's first atomic-powered submarine. At the ceremony, the President of the United States stated: "The military significance of this vessel is tremendous. The engine of the NAUTILUS will have as revolutionary an effect on the navies of the world as did the first ocean-going steamship 120 years ago. * * * But the peaceful signfiicance of the NAUTILUS is even more breath-taking. When this ship has been built and operated, controllable atomic power will have been demonstrated on a substantial scale." In January 1954, the public was informed that this vessel has been launched.

The fact that the NAUTILUS is the *first* beyond-the-laboratory utilization of nuclear energy for power, establishes the Navy in a position of honor and prestige. In keeping with this position, there is the expectation that Navy personnel have some knowledge of, and be conversant with, the applications of nuclear power and its future potentialities. Undoubtedly, selected personnel are getting special training in this regard. Others, however, are less fortunate and must glean their knowledge from popular sources of information. Frequently, these sources are vivid and imaginative, and easily sweep the most analytical reader astray. Unconsciously, he is swept into the fantasy of a millennial "Atomic Age." In the process, professional personnel are unable to draw intelligent and realistic conclusions concerning the technical features involved.

It is the purpose of this writing, therefore, to fill this gap by discussing some of the practical aspects of nuclear energy, particularly, the heat

generating source, when applied to shipboard. After all, a new technology is in the making, and everyone interested should be properly informed.

As a preface to this discussion, however, we must recognize certain limitations imposed by national security regulations. Obviously, we cannot discuss classified design details and specifications of the NAUTILUS and SEA WOLF, or of any other *specific* nuclear power plant under construction or contemplated. To do so would play directly into the hands of inimical interests. Nevertheless, we can discuss certain technical principles and problems in a general way that will facilitate an adequate understanding of the subject, and yet be in conformance with all security requirements.

NUCLEAR REACTORS

The statement by the President referred to the "engine" as the revolutionary feature of the heralded vessel. Actually, this is not quite true. We have to go farther back in the propulsion plant than this, to the primary heat source which generates the steam. Here, we find the conventional marine boiler and fuel oil supplanted by a nuclear reactor and nuclear fuel. It is the nuclear reactor—its design and operation—that comprises the basis of the new technology, and not the engine proper. Fundamentally, then, nuclear reactors are an alternate source of heat for the generation of steam. This, in essence, is the scope of "atomic power."

Nuclear reactors, when substituted for ordinary boilers and fuel tanks, represent the primary equipment for converting the energy of nuclear fission into forms of useful power. They are complicated, expensive, and subject to a great variety of conceivable designs. They provide man with the most concentrated source of energy thus far devised and, in the imagination at least, they have unlimited potentialities. They point to significant savings in space and increased cruising time without the necessity for refueling.

From *theoretical* mass-energy relationships, one pound of nuclear fuel, if completely fissioned, is approximately equivalent to 6,000 barrels of fuel oil (250,000 gallons), or to forty billion Btu's of heat. And, one pound is slightly larger than *one cubic inch!*

Such a relationship is truly impressive. But it leads to all kinds of distorted conclusions. Converting this tremendously concentrated quantity of heat into superheated steam, to say nothing of the biological hazards involved, is a difficult practical matter. The conversion process requires a substantial array of complex coolant piping, critical control mechanisms, remote fuel-handling equipment, massive shielding, novel-design heat exchangers, and so forth. Technical problems, though not insurmountable, are not separable into neat little packages which can be solved one at a time. The result is a physical complexity with a pronounced interlock between methods for utilizing the fuel, fluid mechanics, damage by nuclear radiation, and the corrosion and structural properties of highly specialized metals and materials.

The net philosophical effect is that one should temper his enthusiastic forecasts about the ultimate potentialities of nuclear energy aboard ship—or anywhere else. For example, one should never envision a chunk of fissionable material occupying space about the size of a football as capable of energizing an entire aircraft carrier

for a year or two at a time. This is a fantastic possibility. On the other hand, subsequent to an extensive program of applied research and development, it is probable that the *savings* in space may approach, though it may never exceed, say, 30% of the combined space now used on board ship for the generation of steam. And it is conceivable that a vessel could steam for as long as six months without having to recharge or recycle her reactor. Even this degree of compactness and fuel economy is justification for the study of nuclear fuels and reactors. Whether the operating efficiency and maintenance requirements of nuclear equipment can compete favorably with existing ship's boilers, remains to be seen. This is where the Navy's interest in atomic power is of prime significance.

URANIUM-235

Nuclear fuels liberate heat by the fissioning (i. e., splitting apart) of atomic nuclei of certain materials. To date, there are only three known types of such fuels, namely: uranium-233, uranium-235, and plutonium-239. The figure following each material represents the sum of the neutrons and protons in the center, or nucleus, of *each atom* of that material. The nuclear characteristics of these materials are such that the addition of one more neutron will compound them into an excited state and, subsequently, will cause them to break apart. The resulting kinetic energy of the fission fragments is dissipated in the form of heat and other radiation.

The only natural-occurring nuclear fuel is uranium-235. The other two fuels must be produced artificially. Following more than a decade of experimentation and study, more is known about the characteristics of U-235 than of either of the artificial fuels. As a consequence, it is the most common fuel for the startup of nuclear reactors today.

Natural uranium contains less than 1% of U-235 by weight—0.7115% to be exact. This means that if complete extraction of the U-235 isotope from natural uranium (U-238) were possible, which it isn't, it would require 140 pounds of uranium to produce one pound of fissionable fuel. The method by which large-scale separation is accomplished is known as "gaseous diffusion." Myriads of porous barriers are utilized in an unavoidably, very costly process. For example, assuming that natural uranium costs about $25 per pound, one pound of *pure* U-235 would cost in the direction of $7,500! Rather than seeking 100% purity of U-235, "enriched" fuels are used. These can be produced at any specified concentration of U-235, such as, say, 2%, 5% or more—the rest of the fuel material being U-238. The higher the enrichment level, obviously, the greater the unit cost, but a lesser amount is required for a given reactor. In addition, there is a more efficient burnup of the total fissionable nuclei in the higher enriched fuels.

One of the primary challenges to the design physicist in computing the fuel requirements for a nuclear reactor is to minimize both the total amount of uranium used and its enrichment level. This is not only because of its high cost but also for conservation reasons. Uranium is a vital national resource, not necessarily unlimited in quantity.

A word about the physical properties of uranium: it is a very dense material, half again as heavy as an equal volume of lead. When oxidized

in air, it looks very much like lead, although when freshly cut it is lustrous and white. It is a metal with a melting point in the neighborhood of 2000°F. It is malleable and ductile, and can be machined or cast to any desired configuration. When finely powdered, it is highly inflammable. But this has nothing to do with its use as a nuclear fuel.

HEAT FROM METAL

It is significant to note that we are discussing a *metal* being used as fuel. If we were to take one pound of this metal, or several hundred pounds, we find that we just can't shovel it into a reactor like coal, or melt it and pipe it in like oil, and expect it to generate heat. In the first place, there is a certain minimum amount, or "critical mass," that we must have. Experimental physicists have found that, for a given enrichment level, there is a specific minimum quantity of fuel that will sustain a fissioning "chain reaction." Any quantity less, of course, will not produce the nuclear phenomenon desired. And secondly, we must arrange the fuel with minute care for purposes of control and heat transfer.

If the required amount of fuel for criticality were arbitrarily assembled into one mass, we'd have an atomic explosion rather than a nuclear reactor. This poses the immediate problem of segregating the fuel into small components to facilitate delicate criticality adjustment, and to provide reserve material to keep the chain reaction going as the fissionable nuclei are burned-up. Unlike shipboard boilers, reactors have no air registers to adjust nor oil pressures to regulate. Such regulation and control is, in part, accomplished by the configuration design and spacing of the fuel within the reactor proper.

Another reason for dividing the fuel into small segments is to permit the passage of a coolant for the removal of the generated heat. In an ordinary boiler, the chemical combustion of the fuel produces gases which pass along and around coolant tubes in a rather simple flow pattern. This is not the case in reactors. Instantaneous heat is developed deep within the metal fuel and the only effective way that it can be removed is by a direct interface contact between the coolant and the fuel itself. Unless this is done, the fuel will melt, and so will the structural members of the reactor proper. The removal of heat, therefore, is one of the crucial problems in the design of nuclear reactors. This problem is partly met by the fabrication of the fuel into numerous separate "fuel elements."

FABRICATION OF FUEL ELEMENTS

In order to meet the spacing requirements above, fuel elements must be formed into thin plates, small-diameter rods, pins, bars, pellets or other suitable shapes. Some advanced conceptual reactor designs utilize the fuel in its molten state or as a fused salt, but these fuel element designs are beyond the discussion here. To date, the major attention has been given to the technology of solid fuel elements.

Now, if were to take the required number of bare fuel plates or rods and arrange them in a reactor, what would happen? In the first place, because of the intensity of the fission, microscopic heat "spikes" or bumps would appear on the surface of the fuel metal and present restrictions to the coolant flow. The seriousness of these surface irregularities would depend upon the form of fuel and the type of coolant. At the same time, radioactive contamination would join the coolant cycle. Even without fission, the flow of the coolant will corrode the fuel, particularly so, at high temperatures. Furthermore, the action of a fluid coolant will flake-off, erode, and cause partial solubility of the fuel in the coolant in such a way as to cause deposits of the fuel material elsewhere in the system. These deposits have an adverse effect on criticality control and heat transfer and, consequently, a greater amount of costly make-up fuel is required. It is apparent, therefore, that the fuel elements cannot be placed directly in the coolant medium like the plates in a wet storage battery. Instead, we must add a protective cladding or container jacket.

The cladding material may be aluminum, stainless steel, zirconium or other metal which has the desired nuclear and structural properties. The container metal stops recoiling fission fragments and minimizes the radioactive contamination of adjacent reactor materials. Corrosion and erosion of the fuel, also, are minimized. In short, the metallurgical preparation of the jacket completely seals the fuel and its fission products into small manageable units or segments.

For practical reasons, fuel elements are more generally fabricated into cladded plates or pins. Depending on the type of fuel element, a rigid sequence of rolling, machining, drawing, swaging, and inspection for close tolerances is required. For a reactor suitable for shipboard purposes, from several hundred to several thousand of these fabricated elements would be needed. They are clumped together in bundles for ease of accounting and expeditious replacement. All such fabrication work is done ashore under a "controlled atmosphere" due to the inflammable dust and conservation measures involved.

CORE AND COOLANT

The furnace of a reactor is called the core. Here, the fuel elements are positioned to maximize the capture of random neutrons by atoms of fissionable material. In this central fissioning region, a stringent economy of neutrons must be maintained. Any leakage of them outside of the core, or their absorption by non-fissionable nuclei in fuel, coolant and structural materials, would reduce the reactivity and power density of the core. For this reason, all materials used in the construction and operation of a reactor, including even the welding material, must be selected on the basis of its nuclear compatibility with neutron economy requirements. At the same time, such materials must exhibit structural stability and must not be readily damaged by the intense neutron irradiation. This excludes almost all materials used in present-day boiler construction.

The ideal shape of a reactor core is that of a sphere. This presents the best configuration for the maximum conservation and utilization of the trigger neutrons. Upon each fissioning process, the new-born neutrons speed around, hither and yon, randomly, in every conceivable way. The purely random nature of their direction is

such that a spherical fuel mass best keeps the chain reaction going. However, the construction of a spherical reactor shape has practical limitations. Not only is it difficult to fabricate, but access for the insertion and removal of fuel and the complex channeling of coolant required, lead to other major objections. The next best shape is cylindrical but this, unavoidably, leads to some inefficient use of the fuel material.

Physics calculations for the minimum amount of fuel required for a specified power level of a reactor, are based on the spherical geometry of a theoretical fissionable core. Thus, when we construct a cylindrical core, we must envision that that fuel outside of a spherical area within the cylinder is less effective for the production of heat. Fortunately, however, by the use of suitable neutron reflectors, not only can the total amount of critical fuel be reduced, but also the inefficient area of the fuel can be better utilized.

Any heat generating source requires some medium to remove the heat from the furnace area to other regions for its conversion into steam. In a naval boiler, for example, water-filled tubes perform this function. In reactors, where heat densities are much greater, water may be used but the trend is toward the use of *liquid metals* for the primary coolant. Examples are: bismuth, lead, potassium, sodium and alloys thereof. These low melting point metals permit high temperature operation in low pressure systems. High coolant temperatures are necessary for efficient recovery of power from a reactor and low pressures are conducive to simplified designs. Liquid metals also have high heat capacities and good heat transfer properties so that heat exchange surfaces and quantities of coolant used are small.

When any coolant passes through the reactor core, it is exposed to neutrons which may make it radioactive. During the total time that the coolant is in the reactor, here is a continuous birth of radioactive atoms and also a continuous decay. When the coolant leaves the reactor the birth activations stop but the radioactive decay continues, emitting harmful particles and rays. This decay, or induced radioactivity, necessitates the installation of heavy shielding around the entire heat transfer system in order to protect operating personnel. This requirement has lead to the development of "binary" coolant systems with the great and overriding advantages of providing isolation of the steam and turbine section of the propulsion plant from the reactor proper.

PUMPS AND HEAT EXCHANGERS

In most boilers, water and steam circulation takes place by natural convection, that is, cold water flows downward; hot water and steam flow upward. In reactors, on the other hand, forced circulation generally must be used. Effective and efficient heat removal requires rapid coolant flows that cannot be accomplished by natural means. This is particularly the case with molten metal coolants.

The pumping of molten metals has introduced new hazards and major problems into reactor system designs. When pumping a liquid metal, say at 1000°F., careful design must be made to prevent leaks, spills or accidents to the pumps themselves. Aside from the radioactive contamination in the coolant, any metal leak at this temperature would almost certainly start a fire somewhere, or if not, the leaking

metal would be difficult to cool and control. As a result, reactor pump leak-tight specifications are very rigid. For example, the usually specified leakage tolerance is *one cubic centimeter in ten years!* Such a specification has eliminated the use of conventional rotating or reciprocating seals or bearings in the primary coolant system.

To meet this situation, two approaches have been made: one, the development of a fluid bearing centrifugal pump, and the other, the development of electromagnet pumping. Electromagnetic pumps are devoid of bearings, blades, seals and shafts. They are very durable but their capacities and efficiencies are low. Liquid metal centrifugal pumps, on the other hand, attain higher pumping flows but they are subject to general mechanical failures. Nevertheless, successful pumps of both types have been developed to give satisfactory service in temperatures up to 1000°F.

Because of the previously mentioned radioactivity in the molten coolant and its high temperature, it is desirable to have triplicate pumps at all flows, plus an adequate supply of spares. For example, 10 to 15 pumps might be required for a reactor as compared with two or three feedwater pumps for a boiler. Upon any malfunctioning of a reactor pump, immediate repairs cannot be made. Not only must the inoperative pump be allowed to cool-off thermally, but radioactivally as well, before maintenance personnel can disassemble and handle it. This may take days or weeks. If it becomes necessary to disconnect and remove a defective pump from the system, remote-handling hoists with periscope visual aids are required, together with personnel working under a time limit and behind biological shielding. It also may be necessary to discard a pump entirely, either because of persistent radioactivity or solidifying of the metal coolant with internal critical parts of the pump. As an overall consequence, we must anticipate a considerable number of complicated pumps and pump-maintenance problems when envisioning nuclear reactors on board ship.

What reactors require in the way of additional pumps is partly compensated by the lack of valves. Indeed, valves are conspicuous-by-their-absence in the primary coolant system of a reactor. To be of use, they would have to be quite large; they would have to be remotely operated through the reactor shielding; and, they would have to operate in radioactive metal fluids. Packing against leaks would be almost an impossibility. They would cause no end of trouble, and would be subject to "freezing" in some adverse open-close position. Consequently, insofar as practicable, valve regulating functions are designed into the coolant system by ingenious variations in pipe sizes and pump-speed controls.

When the primary coolant leaves the reactor it goes to a heat exchanger-boiler when it gives up its heat to a secondary coolant, usually water. If the primary coolant is liquid metal, obviously, it cannot be circulated directly through the turbine! Actually, the heat exchanger-boiler (there may be several in the total system) represents the transition from nuclear reactors to regular boiler plant functions. Here, secondary coolant tubes are arranged to extract heat from the primary coolant in adequate quantities and at the optimum steam temperatures and pressures for the reactor plant design. The turbine then is coupled to the total steam plant in the ordinary conventional way.

One major feature that distinguishes nuclear heat exchanger designs from ordinary heat exchangers is that the secondary coolant, if water, must nev-

er, never, come in contact with the primary coolant, if a liquid metal. There are two reasons for this: (1) in the event of leaks in the primary tubes, radioactive contamination would spread to areas outside of the reactor shielding, to say nothing of the loss of the costly coolant involved; and (2) if an alkali molten metal were to meet with water, a violent chemical reaction and explosion would take place. To avoid these adverse possibilities, special concentric-tube construction provides an intermediate barrier or leakage space between the two coolants. When the annulus is filled with, say, lead or mercury, good heat transfer is provided as well as good leak protection and detection.

STARTUP AND CONTROL

The startup of a nuclear reactor, like the startup of any boiler system, requires a programmed sequence of warm-ups and check-offs. This pertains to the primary and secondary coolant loops, sensing instruments, safety devices, control mechanisms and all associated reactor auxiliaries. If we consider only the primary coolant loop, for the moment, we learn that first we must preheat the entire system with a hot inert gas, such as helium, to thermally condition the lines (to avoid cracks and ruptures; to test for leaks, etc.) before receiving the coolant medium. If such a medium is metal, it must be uniformly heated above its melting point then circulated through the system, gradually increasing its temperature to the normal operating inlet temperature of the reactor. This may be up to around, say, 600°F. To preheat the coolant to this temperature, a separate oil-fired conventional boiler is needed as an auxiliary.

The lighting-off and warm-up procedure of a modern marine boiler can be accomplished in several hours. For a reactor, this may require several *days*. Another difference is that the warm-up is accomplished without any heat being generated in the reactor core. In a nuclear sense, the reactor would be subcritical or "cold." Actually, of course, at the preheat temperature mentioned above, the reactor internals would be warmed which is highly desirable in order to avoid sudden and unequal expansion therein.

There is another contrast between an ordinary boiler and a reactor, for startup, and that is the arrangement of the fuel supply. In a boiler plant, the fuel is contained in tankage outside the furnace area, preheated, piped-in under pressure and atomized. For a reactor, the entire fuel supply is contained within the reactor core. The quantity of fissionable material must be sufficient to meet critical mass conditions; to compensate for fuel depletion or burnup for the contemplated cycling time of the core (analogous to maximum cruising range); and, to provide additional reactivity to "override" the fission product poisoning in the core. The total quantity of fuel can only be placed in the reactor when all control rods are in the full "in" or "black" position. Otherwise, a dangerous supercritical condition would exist—spontaneously!

Control rods consist of materials, usually impurities or "poisons," which have an affinity for the non-fission capture of neutrons. These materials, such as boron and cadmium, are alloyed with steel rods in sufficient quantities to rapidly absorb great numbers of neutrons from the fuel matrix. In so doing, the core cannot

go critical and no chain reaction would result.

What is analogous to "light-off" in an ordinary boiler is accomplished by ever-so-gradually withdrawing selected control rods until a critical state is reached. It is difficult to predict with exactness when this will take place, as it depends on the enrichment level of the fuel material, the design arrangement and configuration of the fuel elements, and the effectivity of the artificial neutron producing source (a neutron torch?) within the reactor. Nevertheless, as the rods are withdrawn, criticality is approached and the desired nuclear reaction is started.

Control of the reaction is a function of what is called the neutron multiplication factor, or "k," of a reactor. To maintain the chain, each nucleus of fuel material undergoing fission must produce enough neutrons to make at least one available to induce fission of another nucleus. Actually, from two to three neutrons are born in each fission but not all of them survive to cause new fission phenomena. Hence, if "k" is exactly equal to or greater than unity (i.e., an average of one surviving neutron—there are many thousand fission processes each second), a chain reaction is possible. But if "k" is less than unity, even by a small amount, say 0.9995, criticality cannot be maintained and the reaction will die out.

The value of "k" in any nuclear fuel system is dependent upon the results of four competing processes for the neutrons produced in fission. A fraction of the neutrons may escape entirely from the system; others may be captured by natural uranium (U-238) which generally is non-fissionable, or by other non-fissionable fuel diluents. Or, there may be parasitic capture of a portion of the neutrons by the coolant, reflector, structural material, extraneous substances and other poisons. Then, of course, some of the neutrons may survive to be captured by the U-235 nuclei. But there is no guarantee that this will take place. The first three processes remove neutrons from the system in a non-productive manner. Only in the latter process are other neutrons born sufficient to produce a net gain in "k" above unity. It is the function of the control rods to adequately regulate "k" to manageable values.

There are three types of control mechanisms of interest. They are: (a) regulating rods, (b) shim control, and (c) scram control. Regulating rods permit fine control and micrometer-type adjustments of "k," and for the shifting of power levels of the reactor. Shim controls, on the other hand, permit larger variations in "k" and play a major role in startup, shutdown, and compensation for fuel burnup during operation. As a last resort against the reactor going "prompt critical," and thus endangering the reactor and personnel, scram controls are provided. These controls permit an emergency shutdown - type action either by dumping massive amounts of poisons into the core, or by a bundle or more of fuel elements suddenly dropping out of place. When either of these conditions take place, major procedures would be necessary to restore the reactor to normal operation.

INSTRUMENTATION AND SHUTDOWN

Unlike the procedure of operating personnel in boiler rooms on shipboard today, reactor operating personnel are not in a position to see, hear or feel the results of their actions or inactions. Their endeavors are entirely dependent upon instruments. They operate in a shielded control

room, blind as it were, and all the reactor operation intelligence is fed to them through a complexity of instrumentation and circuitry. The timely and proper interpretation of these instruments would be one of the most important duties aboard ship. A casualty to the reactor could mean casualty and inconvenience to a great number of other personnel.

The function of the reactor instruments is to monitor the various operating factors (e.g., fuel element distortions, coolant flows, neutron density, control rod positions, etc.) in such a way that they are held within desired limits, automatically. Associated safety and interlock circuits seek to minimize the effect of operating error and equipment failures. In addition, many radiation detection instruments are needed to give warning of X-rays, gamma rays, escaping neutrons, etc. Such radiation hazards could be present in stack gases, the ventilation system, the sanitary system, and even "scattered" from the structural parts of the reactor proper, the vessel's hull or the water outside.

The sensing probes of many instruments necessarily are located throughout the reactor and other areas where they are subject to damage by neutron irradiation. Unfortunately, in the first place, because of their inherent nature such instruments are not too efficient. And secondly, their useful life and reliability are adversely affected by the nuclear emanations. These conditions result in the necessity for duplicate and triplicate sensing equipment for the critical factors which control the fluctuating power demands of the reactor.

A distinctive feature of reactor operation is that when a reactor is shut down, heat continues to be liberated for a considerable period of time thereafter. This is due, primarily, to the natural decay of fission products in the core. In the decay process, radioactive nuclei emit their excess energy in the form of particles and rays which produce heat. This heat must be removed in order to avoid undue temperature rises and the consequent distortion and melting down of the entire core. To do this, the coolant system must be kept in continuous operation after reactor shutdown and the excess steam used either for auxiliary equipment or diverted to some form of dummy load. Decay heat is *new* heat generated. It is not like that in a boiler where residual heat continues for a few hours after shutdown such that the steam formed can be dumped to the atmosphere through safety valves. The time-lag of shutting down a reactor may be several days or longer. It is uneconomic to shut a reactor down very frequently and, therefore, reactor installations should be made where continuous operation is feasible.

WASTE DISPOSAL

When a reactor has run its designed core life, it becomes necessary to replace the spent fuel with new fissionable material. This requires novel procedures and facilities. One just doesn't enter the reactor, disconnect the old fuel elements, and haul them up on deck to drop them over the side or to allocate them to the scrap pile. Instead, because of the radioactive contamination involved, disassembly of the elements must be done with remote-handling equipment using some type of mechanical-tong manipulator projecting through the reactor shield breech blocks. When disconnected, the elements first are transferred or dropped into shielded water storage

tanks to allow them to cool-off radioactively. After a few days, they can be transferred to "coffins" (made of steel, concrete and lead) for shipment to central plants ashore for processing and disposal.

At the process plants, the spent fuel elements are decontaminated by chemical processes and the unburned fissionable material is separated and recovered. In general, the percentage burnup of fissionable nuclei in the reactor core is quite low such that the spent fuel has a high salvage value. It must be remembered that the fuel was costly in the first place, and that, further, it has to be conserved for national reasons. In addition, some new fissionable material is produced by "internal breeding" of the nuclear processes. This new material, plutonium-239, is likewise a vital fuel resource.

The final disposal of the fuel waste or "ash," after a sequence of channeling through dissolving and settling tanks, is done in strict conformance with radiological safety requirements. This radioactive waste must not be released to any municipal sewerage or garbage disposal system where it could become a public menace. Either it must be buried underground in concrete vaults, and monitored, or it must be imbedded in concrete and dumped far at sea.

A CHAPTER IN THE FUTURE

One should *not* conclude from the tenor of this discussion that we are in the *midst* of an "Atomic Power Age," so far as the development and utility of nuclear reactors are concerned. To be realistic, one should recognize that all reactors are very costly and complex. The mandate for safety in their design is paramount. Many problems exist and many technological improvements and simplifications must be made before they can be considered seriously as a competitive method for the generation of steam for shipboard power. It also must be realized that such reactors comprise a field in which there is little or no actual operating experience. As an overall consequence, they more appropriately constitute a chapter in the future of the Navy rather than a chapter in the present.

For the immediately foreseeable future, nuclear reactors offer greater opportunity to the Navy than to any other power utilization source. The attractive fuel cycling time and space-saving features, as compared with existing boilers, establish definite tactical advantages. Among these are increased cruising radius, increased speed and increased weapons load. For submarines, the pronounced advantage is that reactors operate independent of air or oxygen supply.

Emphasis on safety always has been a Naval engineering specification so that the operation of nuclear reactors merely requires more care and vigilance. The Navy has the training facilities, the personnel, and can make them available for extended periods of specialized indocrination in reactor theory and operation. Such facilities, at least in part, serve to compensate for the technical complexities involved. The security of vital information on performance and design specifications can be maintained effectively in the Navy. The high cost of reactors is more acceptable to the national budget as "research for defense" than any other type of power-reactor development program. With all of these assets, the Navy is in an enviable position to acquire early knowledge and experience in reactor

technology. Once gained, and when security and economic considerations permit, this technology can be extended to other mobile power plants, such as merchant vessels, and to central-station power plants ashore.

In summary, then, the story of atomic power on shipboard can be expressed in one sentence: We have a few points on the curve of a new technology, but we should restrain against any arbitrary extrapolation of this curve to a millennium—until the Navy has paced the way.

WARTIME MILITARY-ESTABLISHMENT INDUSTRIAL-MANAGEMENT PLANNING

TED POWELL

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Seven years have passed since the close of the most costly and destructive war in mankind's recorded history. In the interim, an ominously prophetic "Spanish War" has run its brief and violent course on the mountainous peninsula of Korea where some five Chinese field armies have been mauled out of virtual existence by relatively small, high-fire-power UN forces in a disastrous "lost face" blunder by the Communists. With present world events showing unmistakable signs of repeating some familiar historic cycles; and with the perspective of time as a sobering backdrop, it might be appropriate at this time to candidly review some of the industrial potential problems of that great conflict.

WORLD WAR II—WAR OF LOGISTICS

World War II has been variously referred to as a war of many things, depending upon the commentators viewpoint, enthusiasm and axe-grinding inclinations. As far as American military professionals were concerned, however, it was in effect a war of logistics—a war of production and sup-

ply—fought out at the ends of some 50,000 miles of transport lines, on four continents, at a half dozen major theatres of operation, pivoted about Allied seapower and based heavily upon American industrial and technological potential. The German high command viewed it as a war in which a landpower failed in its "march around the seas" and lost the war in the North Atlantic in the midst of all its major land victories when Allied seapower smashed the U-Boat wolf packs and began to pour a torrent of American war material into Britain and Russia. The Japanese militarists regarded themselves as unprepared boys sent on a man's errand to assault a slumbering industrial Colossus who barely awoke in time to crush them for their foolhardiness. (Note that one of them had the brazen effrontery to add that—"Next time, we won't make that mistake.") The Russians saw their side of the great conflict as one in which men and land were traded off for time, while a powerful and swiftly striking foe was slowly bled down in a retreating, guerrilla, "meat-grinder" counter-offensive till the poised Allies were ready to strike in the West.

The concensus of professional military opinion here clearly stressed the significance of industrial and technological potential, seapower, logistics and the time element in modern warfare. This is in striking contrast to the gaudy and amateurish science-fiction views frequently encountered in the press today.

WARTIME INDUSTRIAL ORGANIZATION EXPANSION

The management of industry during wartime presents many aspects not ordinarily encountered during so-called "normal" peace-time periods. One of the major problems lay in a swift, ten-fold industrial organization expansion in a relatively short space of two years' time, while simultaneously faced with serious manpower, material and transport shortages and near-impossible production schedules. This situation can be viewed in the light of transient electrical network analysis such as has been so successfully applied to economic society by economists and to industry by military logistics men. A crude analogy can be drawn by firing progressively heavier and increasingly frequent current pulses into a small and badly overloaded electrical system and then hastily patching it up in makeshift attempts to catch up with the amplitude and rep rate signal overloads, with all of the attendant operational errors, jamming, surging, violent hunt oscillations, breakdowns and burn-outs.

In looking back on the war, perhaps the one element which stood out uppermost in mind, was the one which was a striking enemy's most effective weapon—the ever relentless, pressing and fleeting *time*. The mechanization and electronization of modern military machines has endowed them with a mobility, range, awareness and striking power such as to make the time element the vital key to successful over-all military operations. This time factor is carried over to the industrial side of the war effort with all of its pressing significance.

The familiar industrial organization problem crops up much as in the case of military armament planning—sustained maximum preparedness is impossibly costly and the equipment and materiel subject to constant obsolescence; while minimum preparedness is to fail to keep abreast of new technological development and to court military aggression and disaster. To meet this dilemma, the military have developed a compromise "hard-core"

or "nuclei" system whereby intensively trained and superbly equipped military forces are maintained in limited numbers in flexible-skeleton form which can be swiftly and systematically expanded in the event of a war emergency. Similarly, military research work is fostered to keep the armed forces not only abreast of current scientific and engineering advances, but at times, ahead of them.

Industry has found a similar partial solution in military-civilian "parallel line" production plant lay-out, "mothballing" unused plants and equipment, stock-piling vital raw materials, and planning civilian production so that it can be quickly converted to all-out military output with the barest minimum of time, effort and confusion.

However, in surveying the chaotic 1941-6 period, it appears that the industrial problem involved something a bit more fundamental, for in the final analysis it is men and organizations of men that must fight and win a war. As industrial organizations recoiled from the sudden impact of war demands, the familiar "phase delay," "overshoot" and "transient ringing" effects familiar to electronic circuit engineers came into play. What occurred was that management was repeatedly swamped by the unexpectedly enormous demand waves of an unprecedentedly gigantic war. Manpower and materiel requirements, skyrocketed multifold in a matter of months, were somewhat haphazardly met by untrained manpower and delayed materiel.

Emergency measures were taken, of course, to train supervision and workers and to expand production facilities, but as the writer saw it, the basic mistake made was in generally acting only *after* the demands arose and not *before*. What was apparently needed here, was a servo-system, velocity-derivative, "anticipator," negative-feedback, damping circuit technique whereby the plots of the last three wars would be studied statistically in the now familiar "operations research" fashion. Extrapolation dotted curves then could be plotted for a considerable distance into the future so as to enable management to act *ahead* of anticipated war demands to cushion the impact of the demand peaks upon its industrial organizations. Such studies have already been carried out by U.S. Air Force logistics experts.

To illustrate the point, the manpower peak levels of some wartime Naval shipyards jumped from about 7,000 personnel operating on a single 40-hour day-shift to as much as 82,000 working 3 overlapping shifts around the clock, 7 days a week. Over 1,000%, the manpower peak meant approximately that many more managers, supervisors and technical specialists, and this, in the midst of shifting some 4½ million young and able-bodied men into the armed services. One does not get experienced supervisory and technical manpower from employment agencies during wartime. Nor does one increase the development of such trained men to this extent in the space of months, or one or two years, for that matter. (It takes an *already experienced* and *skilled* electrician or telephone man about two years just to thoroughly master the test techniques for properly checking out the sound-powered battle-phone networks on a naval cruiser which might involve some 2,300 battle stations and eight major cross-tied and sector-grouped systems).

What industry might adopt here, is the military "hard-core" technique and plan civilian production plant lay-out and trained picked men in supervisory and technical specialist categories in *advance* of estimated impending war demands. Mistakes would undoubtedly be made, but as the German military men say—"Any action is

better than no action at all." This, in essence, was a typical military production observation during the first half of World War II—too little material, not anough manpower caliber and both too late. As in war, mere arithmetic manpower and manhour numbers meant much less than the *kind* of manpower and equipment one had at his disposal. The Communists made this surprisingly callous blunder in Korea in their costly and bloody "human sea" offensive tactics.

Hand in hand with the trained-manpower advance requirement, is the need for greater industrial organization flexibility so as to permit a much swifter and less disjointed managerial and supervisory force expansion. This can be accomplished through extra "bracketing" and coordinating department and section set-ups and extra "in between" supervisory rates such as were successfully applied in wartime shipyards to provide a smoothly integrated and slide-joint framework upon which an industrial organization can be swiftly and smoothly expanded.

One of the evils in not having adequate reserves of technically trained manpower when war breaks out, is that the small and overloaded core of experienced personnel must carry the brunt of the wartime production load and work 60 to 70 hours per week, sometimes up to 40 hours at a stretch without sleep. This cuts down on productive efficiency and brings on fatigue-poisoning "neurosis" which may last the individual the rest of his life, or produces serious illness which may sometimes develop years after the war is over.

The price paid in human resources is steep here and something to reckon with in hectic post-war years, as was witnessed after both World Wars. Not only combat veterans, but also many civilians have been left with deep and invisible scars after the cease-fire orders have been given.

MANAGEMENT AND SUPERVISION

As has already been pointed out by production men in recent years, the man-hour figures on job estimates can be deceptively misleading at times. They point out, for instance, that only about 1 hour in 5 actually goes into direct production work while the other 4 are eaten up by stand-by, set-up, manpower and material and equipment shifting, information dissemination, ordering, stocking, bookkeeping, clean-up, packing, shipping, etc. Obviously, if only 20% of the over-all total manhour job time goes into direct production, "speeding up" the job or worker appeared to be a fallaciously barren avenue of approach as far as production efficiency was concerned. The answers lay somewhere else in the other 80% manhour time.

In handling manhour estimates, for instance, it was easy to misjudge on an arithmetically logical basis. If a time schedule was cut back and a job was to get done in half the time, one simply doubled the manpower and manhours and halved the production time, etc. As the familiar wartime shipyard quip went—"If in a big rush, shove 10,000 men out on the dock, drop a dozen gangways against the ship, take 10 hours to march them up one set of gangways and down the other and you have your 100,000 manhours in and the 1-month repair job knocked off in 1 day." The paper statistics fail to show that the additional manpower was usually both unfamiliar with the job and usually inexperienced to boot. They also failed to show that jamming 2 or 3 times the manpower in a given

work area, produced overcrowding, interference and loss in productive efficiency. Usually, "Goober's Law" would also operate and several other shops or departments would be simultaneously pushing their jobs in the same area in similar fashion to produce the well-known organized chaos out of regimented confusion. Workers would be literally walking over each other in a bedlam attempt to get their end of it done. Instead of competing against time, they found themselves competing for space instead. Here, the value of inter-departmental planning and coordinating sections was pointedly emphasized. Hence man-hour estimates on major jobs had to be judiciously tempered by such job circumstances when of the rush category.

Repair, alteration and addition jobs manhour estimates presented a problem usually foreign to new construction or production work. The finished product had to fit into an *existing* installation and had to *operate* in conjunction with it. Therein lay the manhour joker. A supervisor sometimes found that his 3-man-day estimate for a minor repair job did not foresee a 2-man-week project of straightening out the old faulty existing installations with their familiar "four wrongs make a right" condition so as to get the new equipments to operate satisfactorily in conjunction with them. This was a constant source of scheduling difficulty and friction between military management and civilian supervision in wartime naval shipyards. Some military people had little conception of the complexity of modern electrical construction and test work and could not see what the civilian was up against in attempting to straighten out intricate ordnance gear. One solution to this problem, might be for military officers to attend training lecture courses for civilian specialists in order to better grasp the civilian's construction and test problem. It is rather significant here to recall that one U.S. military mission in analyzing Japan's defeat in World War II, stated that one reason could be attributed to Japanese leaders' failure to comprehend the complexity of and effort required to pursue the technological end of modern war.

In estimating small rush-job manhour totals, the simple fact was often overlooked that more time might be taken up with assembling men, materials, equipment, information and final clean-up than taken up by the production and test work itself. This also created an unnecessary job scheduling and supervision problem during the war. Some sort of a sliding-scale manhour allowance factor had to be applied to small jobs.

In considering the 80% "non-productive" man-hours, the key to more effective manpower and manhour utilization lay in interdepartmental and intersectional planning and coordinating sections, together with dispatching and expediting groups. Not only the right amount of men, equipment, material and working space had to be at the right place, at the right time, but also *information,* as well. Furthermore, complete coordination between departments and shops was necessary to shuttle departments and shops in and out of the work area in the most effective sequence, or the work in and out of the shops.

A big help here, was the pre-fabrication technique since it allowed a much more effective application of manpower to a project by removing the job from the crowded work area. The pre-fab technique was perfected in British and U.S. shipyards to such a degree that whole ship sections were completely pre-fabbed down to laced, tagged and lugged cable ends which only required to be slipped into the ship connection boxes, the packing tubes stuffed and the lugs screwed

home, while the structural frame was welded and riveted in to the ship structure. In some marine yards, "six of everything" was on hand to keep production going unhindered at top speed.

One of the big hold-up and man-hour loss problems during wartime production work, was in materials procurement red-tape. While a certain amount of red-tape control over stock supplies is required for obvious reasons, management must loosen them up during wartime to allow lower-rank supervision to over-ride "rules-and-regulations" fuss-pots to get the work out on time or before. Time and again work projects would be held up where materials were available but unobtainable because of petty red-tape technicalities. A combat officer would probably not concern himself too much about a proper authority signature for ammo clips while enemy troops were swarming over his sector.

In looking back at wartime pressurized production work, one of the big "snafu" problems was brought about by an inadequate dissemination of information, both job and co-ordination. This is one of the Big Six of large-scale production work (manpower, equipment, materials, information, space and time). One of the ulcer-generators here was incomplete, ambiguous, illegible and incorrect blueprints. What the drafting departments apparently failed to grasp, was the huge "pyramid" manhour loss effect of such prints. What one draftsman failed to do or "didn't have time" to do in one hour in the way of a properly executed print or spec sheet, could multiply itself out into hundreds or thousands of production and test manhours by the time dozens of copies of the print circulated through crews of production men and weeks of production time. One of the more amusing wartime blueprint merry-go-round items, was to be "short-cut" routed through a half dozen prints via the "see print so and so" reference note route, only to be finally and baffingly referred back to the original print again, sans the necessary info. Fuzzy and illegible prints were another headache, as were unsystematically arranged data. Blueprints *must* be complete, detailed, unambiguous, self-contained, systematically organized and completely legible if the work is to get done quickly, efficiently and correctly. The blueprint is the brain that guides production work and if it be lame, the work will be bungled.

A similar manhour "pyramid" loss effect was produced by incomplete and unsystematically arranged materials stockrooms. Some stockkeepers never set up a stock room in neat alphabetical and numerical and functional order since that entails much too much sweat. Others are of the "worry wart" type and an "amateur night at Fox's Fabian" attitude that if they order enough materials to keep a completely stocked stock room, management might get the idea that they are inefficiently squandering government or corporation funds or "wasting" them. The criterion for a properly organized materials supply stock room is quite simple. It is one into which any outsider can step, quickly orient himself and locate anything required to complete any job handled by the department in question. Where, O Lord, do we find such a Garden of Eden?

In setting up their wartime production organizations and plants, production men might do well to carefully study the close team-work and communications techniques as now employed by modern military service arms, and the heavy emphasis they place upon them. This might be philosophically likened to the simultaneous "awareness" of a living creatures's

nervous system to both its internal organisms and external environment.

One of the causes for loss in productivity of worker personnel could often be traced to severe working conditions out in the field. This included heat, stale air, noxious gases, poor lighting, noise, vibration, overcrowding, cold, etc. Some of this is unavoidable in heavy industry and construction work, which also includes accident hazards. On the other hand, a good deal of this can be avoided by proper equipment, safeguards and enforced regulations. The writer once heard a Navy captain comment after coming down below decks on a cruiser construction job into a welding-gas filled compartment, "A man must pay with ten or twenty years of his life for working under conditions like this!" America today is wasting her human resources much as she once squandered her natural wealth. Too few of us today realize that the former is much more precious than the latter. While the Navy Department has taken an enlightened and progressive attitude with regard toward industrial safety and health hazards factors, much still remains to be done with regard to human damage caused by noise, fatigue, inadequate air supply, industrial chemicals, etc. When war comes, we must hire cripples and misfits, hence we cannot afford to waste our humans.

THE MILITARY-CIVILIAN LIAISON PROBLEM

In the case of civilian production establishments run by the military, a ticklish personnel problem cropped up in the way of officer-civilian relations. That some friction would develop, even with ideal personnel material, seemed inevitable. This was true not only from the two-cooks-on-one-meal viewpoint, but also for the simple reason that the organization and command philosophies of military and civilian organizations tend to be somewhat incompatible. The military, of necessity, rely on a straight "chain of command" system, with implicit and unquestioned obedience to "rank" and orders. One does not go into detailed conferences, collegiate debates or philosophical discourses in the midst of combat. The major weakness to this "die is cast" set-up, of course, is the lack of an error-sensing, servo type, liaison feedback loop between the control and drive points of the system. Once initiated, the system actuates itself "blind" for a time inflexibly towards a pre-planned goal in a do-or-die fashion, for better or for worse, regardless of the immediate subsequent circumstances or shifting developments. This is partly the result of necessary long-range logistics preparations behind most military operations. For this reason, among others, the Germans were defeated in North Africa, for the British learned to anticipate their inflexible tactics.

The military also rely upon a blanket "rules and regulations" system, with no leeway or exceptions permitted on an individual judgment basis. The huge masses of manpower, equipment and material handled; the hectic state of constant flux common during wartime; and the entangling presence of the familiar wartime "sea lawyer" and "angle bird" type of personnel, make this more or less mandatory.

To some extent, the modern military service arms are getting away from this "Prussian Heel" command philosophy since it conflicts with the swift and mobile guerrilla nature of modern warfare. Nevertheless, the mistake made by some of the wartime home-base and rear-echelon base mil-

itary establishment officer management, was to attempt to run civilian personnel with such military dispatch. While the civilian was compelled to submit to such arbitrary discipline during an emergency wartime period because of wartime manpower freeze regulations, such tactics were doomed to failure and only resulted in loss of morale, balky submission, personnel friction, loss in productivity and a rash of experienced personnel resignations at the conclusion of hostilities. To state that irreparable damage was done here, is, to put it mildly, understated. This situation has been cleared up to a large extent in post-war years, but will be discussed here in blunt detail anyway since many of the points have a bearing upon civilian organization management.

Aside from the basic difference, between military and civilian organization and command, there also are some more subtle psychological aspects. Once a man dons a military uniform, he enters a psychological world apart and in his eyes, a civilian simply doesn't "belong" and is an "outsider" in a military establishment. On top of this, during wartime (and sometimes justifiably so, unfortunately) he is regarded as a "draft dodger" and a "time-and-half goofer-offer," even though he may have been employed there for years prior to the war, frozen in his job by wartime manpower acts, reasonably industrious and had made a volunteer service offer to one of the military services. Such an attitude on the part of some military men (many of whom were wartime draftees themselves, incidently) was bound to show up in officer-civilian relations, with no good to military production accomplished.

To still further aggravate the personnel situation, during wartime most military men were not military professionals at all, but reservists or draftee civilians in a new and unfamiliar set of clothes. While this is a perfectly normal wartime condition, troubles developed when certain psychological personnel types were involved. The most troublesome cases involved men who as civilians held down petty hack jobs involving no authority, responsibility or supervision. Such men who suddenly found themselves hurled into the whirling maelstrom of war and abruptly promoted onto positions of authority and responsibility, sometimes reacted in unpredictably neurotic fashion. The familiar "Casper Milquetoast to Simon Legree" psychological transformation would sometimes take place in the familiar "law of compensation" fashion. The little boy stumbling around in the big man's shoes found himself inebriated on a potent brew of rank and authority, the masochist turns sadist, and another "little Hitler" was born.

Others reasoned that they were in only "for the duration" and operated as rate-happy opportunists out to get all they could as fast as they could, regardless of who or what got hurt in the process. Still others were the "worry wart" red-tape buck-passers who found the job much too big for their britches (but the pay not too fat for their wallets) and snarled up things in a morass of double-talk, petty technicalities and buck-passers. Then there were the arrogant, insulting, sadistic "silk whip" type who wrecked morale far more effectively than the most carefully calculated enemy propaganda. The damage such supervisory personnel, both military and civilian, have accomplished in wartime military production establishments, made the efforts of enemy saboteurs appear rather superfluous.

The lesson taught here by the war appears to be three-fold. One is that the higher type of officer personnel cannot be shipped off to home-base training centers and the combat fronts in wholesale fashion where admittedly

they are so desperately needed. A broader, over-all logistic viewpoint seems more appropriate and some executive type officers (and the writer encountered some unusually excellent ones during the war) should be sparsely rationed out on a rotational basis among the home-front and rear-echelon production bases to set as circuit impedance - matching, tuning, coupling and damping elements to more closely couple, tune and stabilize the military-civilian networks for greater and less distorted output. The second is to set up adequate personnel and psychological test procedures for officer personnel being assigned to civilian production management divisions so as to weed out the psychological misfits *before* they do their damage. The third is for the military services to set up a program for the thorough training of officer personnel in industrial administration and personnel management at the various military service schools. This has already been partly accomplished, particularly by the Navy Department.

PERSONNEL PROBLEMS

As already mentioned, war is not so much a conflict of nations or military forces as it is a struggle of man against man. Fundamentally then, the outcome of a major war is to a large degree determined by the caliber of the individual, both leader and led, on both sides of the conflict. Therein, as the writer saw it, lay one of our major military weaknesses which was exploited by the Axis powers in the last war with considerable success; and one which the Communists will play upon even more in the event of another world war. For the next one will undoubtedly be "absolute" war, with everyone automatically a combatant whether he or she chooses to be one or not. Modern science and technology have made it so, paradoxically enough.

Viewing the human from a purely impersonal viewpoint, his military potential might be arbitrarily broken down into four general categories—physical, psychological, educational and experience.

With regard to the physical aspects, draft board statistics disclosed a rather shockingly low average physical standard of our manpower. Similarly, much of the civilian wartime production personnel was poorly equipped physically to handle heavy, dangerous, strenuous or long-work-hour jobs. This is paradoxically in sharp contrast with the high standard of living existing here and the magnificent athletes and pilots produced by the U.S. Why then, one might ask, this high contrast ratio? The answer where our youth is concerned, probably lies deeply rooted somewhere in our outdated schooling system, decadent social attitudes and cynical post-war psychology.

A casual study of the Spartan, Roman, Swiss and Czechoslovak Republics, indicates a high respect for athletic prowess and physical development and a concerted attempt at developing it on a mass scale. While this attitude does exist in the U.S. psychologically, there is not the organized mass effort to physically develop *all* of our youth. We have too much of the small specialist performer vs. mass spectator group attitude, with a resultant detrimental effect upon our general physical well being. We also have too many industrial workers who cannot see or hear well, climb scaffolds, lift heavy gear, or withstand more or less necessary severe industrial noise, heat, foul air and long work hour conditions. And we have much too many of our youngsters who do most of their

physical training in gin mills, parked cars, street corners, pool parlors, and "social" clubs.

Compulsory physical training, athletic participation on a mass basis and a greater stress on proper diet, health and physical development education in our schooling systems appears to be advisable. "Parlor generals" may paint spectacular pictures of impossibly costly science-fiction warfare of the future, but as always in the past, in the final analysis it will be the unsung and unknown "guys on two feet with guns in two fists" who will have to settle the outcome of the next major war. Even if such warfare was possible to finance, such technological combat would obviously place even severer physical demands upon the combat men than required in the past. The next war will not be won by social-lion softies or gin-mill zoot-suiters, atomic push-buttons or no, whether they be combat-front fighters or home-front producers. For the home front will also be a battle front in the next war.

Our manpower's educational equipment also had many shortcomings. During wartime, women take the place of men in both industry and war, while men take the place of women at the combat fronts in many respects (phone operators, cooks, messengers, aides, typists, medical assistants, etc.). This points to one of the minor flaws in our schooling systems, at least where war is concerned. While this usually brings on humorous comments, it might be worth while to train boys to some extent in cooking, sewing, homemaking, etc., while girls might take up some woodworking, drafting, sheet-metal, light machine-shop work, etc. When war comes, the youngster is better prepared for the emergencies produced by it, whether they be military or industrial. Such training is of some value even in peacetime.

Our academic system might also be a bit outdated in too much stress upon cultural subjects and the human sciences. While this can be a hotly debatable point, the harsh fact remains that modern society is technological and so is modern war. Hence only a technologically trained nation can hope to survive in the struggle of industrial giants that will probably continue to crop up every generation or so, human nature and the world's political structure being what they are. Our educational programs may be placing too much stress upon general education and too little upon technology. While there is nothing basically wrong in teaching a youngster about Caesar in Gaul, Peter picking a peck of pickled peppers, or the soliloquies of Plato, this culture will do him infinitessimally little good while crouching in a combat-front fox-hole, sprinting for an atom-bomb shelter, or helping to build a battlewagon or strato-bomber. Even if a youngster intends to enter one of the non-technical professions, a certain amount of schooling in mechanical trades and technical subjects will stand him in good stead for the rest of his or her life, war or no war.

We often boast of our highly industrialized American way of life, yet seldom pause to realize how many of us cannot even adjust a carburetor, fix an electric iron, or make a crude sketch of a mechanical part required for the repair of a defective article. This points to another flaw in the gaudy descriptions of futuristic supergimmick warfare—where to find all the technological supermen to run all the shiny multi-million-dollar push-buttons.

Another shortcoming in our schooling systems appears to be in too much emphasis upon academic material and too little upon practical subjects which would better fit a youngster to face the business of living in peace

and surviving in war. A study of wartime industrial personnel disclosed a lamentable ignorance of even the elements of industrial safety, industrial hygiene, electrical hazards, drowning precautions, fire prevention, explosion hazards, traffic safety, emergency first aide, disaster handling, proper work diet and clothes, etc. Youngsters might also be taught driving, swimming, woodcraft, dancing, social conduct, sex facts, and encouraged in mechanical hobbies such as supervised "hot-rodding," model plane, model auto, model boat work, etc. This is now being attempted in some of the more modern schools, especially those for so-called "advanced" students.

One of the troubles with the proper dissemination of information in large-scale industrial work, is the prevalent use of script handwriting which is sometimes unintelligible even to the writer a few days after it was scribbled down. It is now customary in many engineering fields to require all technical memos and notes to be hand-printed in straight block type. With some practice, it is possible to hand-print faster than most people can script-write. Industry, business and the government would probably be saved a good deal of grief and vast sums in lost man-hours if students were required to do all their work in print form, with the standard script confined to signature and formal letter work. Chicken-scrawl script has caused a lot of trouble in wartime production work and should be done away with in technical and industrial fields.

Another information dissemination problem was caused by an inability of lower-rank supervision to transmit explicit and unambiguous orders down the line; or to prepare clear and concise job status reports. Here again, one might point to certain shortcomings in our academic systems. A casual glance through a few scientific and engineering journals discloses the fact that even supposedly highly educated and intelligent professionals are often unable to get information across to a reader. This might get a bit more attention in our English classes by trading off a bit of culture for some clarity. What is needed is not grammatical and literary composition, but concise and informative composition.

American schools also traditionally avoid military subjects and any suggestion of military training. About the closest they approach this is in physical training drills and Boy Scout Troop activity. A military man will point out that it takes a professional soldier about a year to learn how to properly proceed against simple ground fire; another year to learn all the tricks of staying alive under mechanized and aerial unit fire; and a couple more years to thoroughly master the operation and maintenance of a limited assortment of weapons. This does not take into account complex mechanized or electronized "push-button" equipment. Yet we take farm boys and office clerks, run them through a few months basic training and optimistically hurl them into the flaming maw of modern war—while we glibly talk of "atomic" and "push-button" war. Similarly, we expect untrained home-front civilians to intelligently face the assaults that may be launched against industrial centers and to protect both them and themselves. It would seem that some sort of basic and elementary form of civilian military training should be incorporated into the physical training programs of our schooling systems.

Certain psychological shortcomings have also cropped up in both our industrial and military manpower during the last world war and in Korea. These might be traced back to several fundamental factors—animal instinct, home environment, schooling and the social and economical environment. A

discussion of the first item would be out of place here since the writer's quarrel is not with Mother Nature.

One of the big wartime production problems was a lack of sufficient co-operation between individuals and groups of individuals. One of the remarkable phenomena encountered in the animal world is one referred to by biologists as "hostile cooperation." Animals of the same species will compete desperately against each other for food, mates and stomping grounds, yet band solidly together to fight off outside enemies and a harsh environment. To some extent, this is also true of animals and plants of different species on a similar "hostile dependence" basis. By a ruthless process of Darwinian trial-and-error elimination, a delicate cooperation-conflict balance is arrived at to the over-all benefit of all concerned, or the specie do not survive. This is a most interesting object lesson for industrial management to ponder over. Why is it, one might ask, that supposedly intelligent humans cannot more often arrive at a similar mutual-benefit balance in their operations? Workers, supervisors and executives are in competition with each other for recognition, promotions and pay boosts, yet must not allow this to interfere with the team-work and cooperation necessary for getting the most accomplished with the greatest net benefit to the organization as a whole. A similar condition exists in the case of athletic teams. It requires intelligence, tact and *integrity* to draw the "what-the-traffic-will-bear" line here. Too many wartime individuals operated on a "hostile cooperation so long as you get the friendly short end of it" basis, with detrimental effects upon the war effort.

In the case of supervisory and executive personnel, there was a problem with unpredictable post-promotion behavior already mentioned in the case of military officers. As one highly capable electric shop foreman (superintendent) at a Naval Shipyard once told the writer—"One big cross all executives must bear, is in not always being able to gauge just what a promotion might do to an otherwise apparently good man. Make him and then have him metamorphasize into a worry-wart, dictator, politician, buck-passer or cigar smoker and brother, you are stuck with him. If you turn around and bust him, you find yourself with a demoralized bum on your hands. Fire him upstairs to keep him from gumming up your works and you unload him on somebody else to do his damage elsewhere and silently advertise to all and sundry that *you* are the Blind Tom who made the stiff. You just can't win if you happen to guess wrong. But how in Sam Hill is one to know, even with the assist of an ouija board? Human nature can be so confoundedly diverse that there is just no figuring it out sometimes." The answer here seems to lie in systematic psychological and aptitude tests for all personnel moving up into supervisory and management ranks. The costs would be justified since promotional mistakes can be even more costly in the long run, even though they do not readily show up on hollow paper statistics.

In the case of coordinators and expeditors, one occasionally ran into the typical politician type who would operate so as to make a $50 job out of a 5¢ one, entangle the job in a snarl of red-tape and technicalities, shout for more manpower to get his work out on a "make-seven-copies-of-everything" basis and then demand a promotion as befitting such an imposing and productive organization. (As one U.S. Naval officer once commented, no one ever seems to ask for a promotion and raise for having been able to get his work out with *less* men). Such tactics earned these "operators" the title of "bottle-neckers."

The military were troubled even more by this type of personnel than were civilian organizations. Where planning and dispatching sections were concerned, politics and handshaking reared their tentacled heads to create the title of "plotting and destruction" departments. Such opportunitist personnel caused a good deal of trouble during wartime production efforts. Here, wartime management must exercise great care in picking "team" men for such vital positions who will operate with a minimum of hostility and a maximum of cooperation. Again, psychological and aptitude exams seem to be indicated.

Hence the big problem in getting things done was not always so much shortages in time, materials, equipment and manpower, as much as in shortcomings in the manpower itself. And because of such self-centered and neurotic attitudes, others sometimes had to pay a tragic price for it somewhere on a distant battle front. More than once after a difficult wartime production situation was finally unsnarled (which should never have developed in the first place if high-caliber personnel had been involved), one would ponder over the eternal cussedness of human nature and ask himself—who are we supposed to be fighting anyway, the remote enemy on a distant combat front, or ourselves at home? As one U.S. military man so aptly put it, we won the war not because of ourselves, but in spite of ourselves.

The question that arises here is—what makes so much of our industrial personnel tick so erratically and inharmoniously? Part of the answer lies in the competitive and localized home and school environment. The child must top others on his block and in his class, not that he may become a better cog in society, but that his parents and teachers may sound off. Father must have a big car not because he or his family have need of one, but that it tops what Mr. Firthquirt across the way owns. Mother must have the whole house redecorated not because it will make the family any happier, but because Mrs. Broadebeame next door had her front porch done over. Daddy doesn't associate with certain men in the town because they are 'common" workmen, have a pigment in their skin, a sweep to their nose, don't belong to his church or lodge, or live in the "wrong" part of the town. The child is reared in an atmosphere of misdirected ego, localized allegiances and tribal tom-tom taboos. He becomes a victim of a psychological jungle world of outsiders and competitors who "don't belong," must be "topped," "torn down" or "out-foxed."

This is subsequently carried on in schools with their intense intra-mural and inter-scholastic competition where one must excel or win at all costs in typical "murder them bums" fashion, not to have accomplished something or played the game well, but merely for the sake of winning and excelling on the report card and scoreboard. The misguided emphasis is placed upon the end result and not the purpose. Eventually, the young adult carries his petty juvenile and adolescent battle banners into his profession or trade to carry on his Quixotic Freudian crusade against a world full of his misguided competitive duplicates. Such an individual is psychologically misfitted for a role of "hostile cooperation" in any complex organization in a modern technological society on a "complementary interdependence" basis, to quote a Sylvania engineer's phrase. This is true of any military, industrial or technical organization. Hence we have the situation in many industrial corporations where each section and department regards the other as a separate and independent corporation (non-productive, of

course), to be handled with a minimum of cooperation and a maximum of buck-passing and criticism. This is inevitable since the individual's psychological patterns were set in his infant and juvenile years long before he was ready to take his adult place in society.

What appears to be necessary here, is a reorientation of the youngster's ego drive and the development of broader allegiances. The old Roman axiom of "the most good for the greatest majority" and the Nazareth Carpenter's admonishion that "he who wrongs another, only wrongs himself," seem like most appropriate stars along these youth training lines.

Another psychological flaw found in our wartime civilian and military personnel, lay in a lack of initiative and an inability to promptly handle emergency or usual situations. Part of this might be attributed to our academic systems where originality and nonconformity are frequently penalized and discouraged rather than fostered. They tend to turn out too many routine hacks and mass-produced stereotyped mentalities. The stress lies too much in a conformist attitude and a memory accumulation of routine textbook data, rather than in an ability to reason and apply factual data, or think along original and creative lines. The student is also given the impression that what is taught him from textbooks which were obsolete before their writer even finished writing them, are the Eternal and Universal Laws and Truths Of The Universe and nothing more is to be known or questioned concerning them. A classic example of this static academic attitude was a provoked German mathematics professor's advice to a young and unconventionally thinking math student —"You are only wasting your time and mine. I advise you to drop this subject as you will never amount to anything in it!" That student is today recognized generally as the greatest mathematician of all time—Albert Einstein.

Part of this conservative conformist academic attitude is partly due to a fear of radicalism of any sort, or what the Japanese refer to as "dangerous thoughts," or American ultra-conservatives call "subversive thinking." Nevertheless, this mental-hack schooling approach turns out a scholastic product ill suited to the complexities and demands of a modern technological society. The crying need is for individuals who can think originally and act for themselves, both on the battlefield and production home-front, and not simply spout off neatly categorized textbook data by rote, or operate eternally according to the rules and regulations.

Still another psychological flaw in our wartime personnel was a certain vulnerability to enemy propaganda. This can also be partially blamed upon our educational system, partly for the above reasons and partly because of the slanted historical and economic data presented to students as so-called "facts" and "laws." In comparing a British, German and American history text concerning the American Revolution, for instance, one is left in some bewilderment. The reaction usually is — are they all talking about one and the same war, or are history books the products of propaganda mills? When a war-torn combat man or worried industrial worker with a close relative at the front is exposed to enemy propaganda which informs him of some disconcertingly detailed and consistent historical and economic data sans the usual coat of academic varnish, he may become a bit bewildered and demoralized. In fact, he may go so far in his disillusionment as to actually turn himself over to the enemy in his war-strained emotional state. This has occured many times in U.S. atomic plants during the second World War

and at the Korean battlefronts. Hence instead of stemming "subversion" and "disloyalty" by resorting to slanted and fictionized history and economics, the over-cautious "professional patriots" neatly play right into the Communists hands. For no falsehood is more damaging than a half-truth, for it will be believed.

Such tactics also tend to create a cynical and disillusioned type of youngster who soon enough begins to lose faith in everything in general with a typically morbid, post-war, "lost generation," teen-age attitude of "everything's a lousy racket and a big con and we're the big suckers what's being took." Such psychological material is something less than ideal material for any type of organization. What seems to be in order, is a general housecleaning of our outdated and inaccurate school texts. As the old con man's axiom goes—"You can't take an honest man." Just so, one cannot easily delude or demoralize a man armed with solid facts and taught to think for himself. When war comes, it is far better to have balky, intelligent and spunky thoroughbreds on hand than submissive, misguided and panicky sheep.

One of the big industrial personnel problems during the war was caused not only by the sudden jump in the wartime manpower forces, but also in the wider array of personnel types that makes its appearance on a statistical probability basis. Alongside the familiar industrial worker types, appear the worried housewife with a man at the war front, retired business man, war-displaced small business man, ex-prizefighter, showgirl, musician, model, artists, etc., all more or less intent to do their war bit. Along with these, come a small percentage of assorted shady characters from the criminal world. During a wartime emergency, there is not enough time to thoroughly check on all personnel before hiring, nor is it any time to get too fussy about personnel standards. The net result is a kaleidoscopic cross-section of all humanity itself which was most interesting and instructive to observe at first hand.

Educational though this situation might have been, it produced an almost unmanagable supervisory problem at times. The usual personnel regulations effective enough during a normal peacetime period simply broke down when attempting to handle certain wartime types of people, particularly when manpower shortages and regulations tied them down to their jobs, and the pressing time shortage problem hog-tied supervision. The net result was that supervision found itself harassed and quagmaired by a small breed of phonies and deadbeats and entangled in a morass of petty technicalities deftly woven by those who had spent most of their shady lives expertly finding loopholes and the easy way out. This exposed supervision to "lost face," loss of discipline, lowered production, wasted time and unnecessary mental punishment. This was particularly true of governmental and military establishments with their legal and red-tape technicalities.

Management must loosen up red-tape and give supervisors more effective control over such personnel during wartime if it is to operate at full efficiency. In particular, the wartime manpower freeze must be thawed out enough to allow immediate dismissal of objectionable personnel on justifiable grounds. To hold such obnoxious individuals on the grounds that during wartime every bit of manpower helps, no matter how shoddy, is an obvious fallacy. In the long run, it would have been cheaper to pay such help a weekly salary and send them home where at least they couldn't do any damage to production out of all proportion to their number. The psy-

chological effect upon such people of an enforced job freeze was much like informing criminals that they could not be taken away to prison—with obvious consequences.

A sort of post-mortem personnel problem arose at the close of the war in the case of long-term employees. During the war, most of the warplant workers who had been employed there prior to the war, were of necessity frozen in their jobs by the War Manpower Act, even in spite of military service volunteer offers by some of them. If the war worker attempted to quit his job to enlist, he could not be accepted by any of the services without a 1A classification. If he were a government employee, he was also informed that if he refused to go back to his job, he would be dismissed with a dishonorable discharge for disobeying wartime regulations and would lose all his civil service rights. When the war was almost over, the GI Bill of Rights was passed to take care of the war veterans. Many civil service workers then found themselves ousted from their jobs, sometimes after 20 or 30 years service. The ironical part of all this, was the fact that some of the civilians had attempted to enlist and others had to work in military danger areas, while many of the so-called "veterans" who displaced them were draftees with only a few months home-base training and were what combat veterans sarcastically referred to as "cabaret commandos" and "boot camp night-fighters." This created a personnel problem and serious loss of morale at many governmental establishments and caused a rash of resignations of highly specialized and heavily experienced personnel. The damage done here was considerable.

It appears that our lawmakers might look into this knotty governmental personnel problem a bit deeper and set up more equitable rulings in balancing up military vs. civilian service point ratings. While combat veterans must unquestionably come first, by the same token, for a 3-month boot-camp trainee to displace a man who had spent 33 years of his life helping to build warships for his country, seems like carrying wartime patriotism just a bit out of bounds.

A LOOK INTO THE FUTURE

Thinking people all over the world, especially those who have had any direct connection with the last two wars, wistfully hope for a better kind of a world for their offspring than the troubled one they knew. But the recent trend in world events makes such a wish a rather forlorn one. Harsh and unpleasant though the facts may be, they must nevertheless be squarely faced. In the streets of Berlin, in the mountains of Greece and Korea and along the propaganda lanes of the globe, the opening battles of World War III have already been fought!

The Communist game is a fairly obvious one and consists of rough-neck bullying, accusing, stalling, confusing, dividing and "Spanish Warring" about the globe so as to systematically bleed down the democracies and divide them, while they build up their material resources and industrial potential to match our own. Then and only then will they risk a strike —and one which will come suddenly and without warning. The Communists do not intend to make the same mistake made twice by the Germans and once by the Japanese. They now know that to win a major war, it is necessary to first knock out the enemy's industrial potential as well as its outermost military bases.

The spectre of a tragic December Sunday in 1941 prophetically points to the possibility of a shocked and dazed democratic world awakening some explosive night within the next 10 years to find dozens of its major industrial cities pin-point paralyzed and flaming at their industrial, transport, communications and research centers, with dozens of suicide Red paratrooper divisions swarming over them to complete the disorganization and demoralization job while the gigantic Red Bear gathers himself for his lumbering assaults. The historic precedents have already been set and it requires no particular prophetic genius to plot a dotted extrapolation curve into the near future.

One of the lessons taught by a study of the effects of the costly and wasteful Allied serial bombardment assaults against German industrial cities, and subsequent German countermeasures; and the scattered and smothering decentralized-guerrilla Russian defense tactics against the too-swiftly-advancing Germans who found themselves small men swinging their clenched fists in big rooms full of feathers, is the necessity for spreading out U.S. industry evenly over some 6 million miles of territory. This is to better absorb a possible initial surprise assault; eliminating the possibility of a "haymaker" knockout blow such as has been brought within the realm of possibility by the new, highly over-overly costly nuclear-fission missiles; and to prevent the temporary crippling of any one vital war industry. This has been accomplished to some extent, quietly and slowly, since the close of World War II.

In planning and preparing for what now appears to be the inevitable, American industry must cut itself free from the time-delay red-tape shackles of a normal peacetime economy. A nation's survival in another world war lies not so much in heavy rearmament and perpetual vigilance, as in the ability to absorb a smashing military surprise thrust, recoil swiftly and strike back with even greater speed and paralyzing power. Its science and industry must not only be capable of recovering quickly, but also converting to war, expanding swiftly and producing immediately in torrential volume. The key to survival lies not in "No. 1 armies, navies and air forces," but in crushing retaliation. This is the one and only factor which will ever deter the Communists from open military aggression against the democracies when their industry fully recovers from the wholesale destruction unleashed upon it both by the advancing Germans and the retreating "scorched earth" Russians.

As more than one military professional has pointed out in recent years, the U.S. now stands in greater peril than in the dark days of the fall of 1941 when Britain teetered on the edge of the dark precipice and all that stood between a bomb-shattered London and the exhausted German panzer divisions at Dunkirk were 20 miles of water, Allied seapower and a battered handful of magnificent RAF pilots. However, the military men have differed as to just where our real danger and greatest weakness lie, depending upon their service affiliations.

Perhaps the answer to this can be found in Gibbon's penetrating analysis of the causes for the disintegration and collapse of the spectacular Roman Empire. For as it has so often been said before—the past is prologue to the future. Our menace lies not in an inadequate multi-million-dollar radar "fence" which can be RCM and RCCM countermeasured into near-total uselessness; nor in inadequate fleets of bankruptcy-priced planes which can be blasted from the skies with guided rockets and radar-fuzed shells; nor in insufficient armament and fortifications which can be precisely nullified

by a minutely "loophole" planned sneak thrust and by newer enemy weapon designs. The big chink in American armor is the same which has brought about the downfall of other great civilizations in the past—a growing moral and physical decay.

As one governmental official recently commented, we live in a paper dreamworld of false paper values, inflated paper money and slanted paper statistics and have failed to squarely face the harsh realities of cold fact. In the deterioration of the marriage and home ties, the rise in dope addiction and sex perversion, the blatant corruption in government and politics, the psychotic driving pursuit of monetary gain, the unethical tactics in business and the growth of juvenile delinquency (adult negligence), we see the danger signs of weakening cracks in an imposing and massive structure. But most alarming of all perhaps, is the hypocrytical, cynical and unconcerned *attitude* toward our wholesale backslide into moral decadance.

Part of this can be blamed upon certain segments of American leadership which has failed us in setting a corrupt example and in stressing false values. Most all of us adults have self-centeredly and short-sightedly failed our unguided and goalless youth. As they say in the Navy—a good skipper and a good ship and a good crew. In Gibbon's historical classic and in a Frenchman's "The Gravediggers of France," are graphically portrayed the blind folly, treachery and national suicide that is born of greed, corruption and vice. The American gravediggers who did not dig quite deeply enough at Pearl Harbor, are busily excavating again today for another try. As the Reds themselves have stated, they need not extend themselves or risk an open conflict to defeat us, necessarily, for by properly maneuvering against our weaknesses, we can be jockeyed into defeating ourselves.

Our big problem then, both military and industrial, is buried not so much in insufficient material, machines and time, as in our inadequate human resources. As one Russian Army general told a group of his officers a few years ago—"The next war will be won not by machines, but by men—not by atom bombs, but by morale!" Starkly realistic and prophetic words from one who had helped stave off one of the most powerful and efficient military machines ever launched into war—words which he may yet live to see fulfilled.

To bolster our human and industrial potentials, not only must American industry decentralize, streamline, become more elastic and "hard-core nucleize" to allow for explosive wartime expansion, but must also press to revitalize our archiac academic systems to train and develop the kind of men and women that a future "absolute" technological war will require. What will be needed, will be humans with initiative, stamina, courage and self-reliance who morally, psychologically and physically match our intellectual and technological advances.

But above all, as one U.S. Army officer recently pointed out in discussing liaison officer requirements, men with a selfless and rock-bound *integrity* will be needed. If we cannot find enough of such men, as was the case in World War II, then we had better go about growing and developing some. For the trying time may not be too far off when we shall be badly in need of them.

CALCULATION OF THE THICKNESS OF HIGH-TEMPERATURE STEAM PIPES

ACKNOWLEDGMENT

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In recent years the temperature at which power stations operate has risen to such an extent that not only have special alloy steels to be used for the pipework, but it is no longer possible to close one's eyes to the fact that creep, even with these alloy steels, will be taking place to an appreciable extent during the life of the station. Many theories have been put forward for the basis on which the stresses, and hence the required thickness, of steam pipework should be calculated under these conditions. Some of these, however, are contradictory and all of them are based on assumptions regarding the creep behavior of steels of which the true facts in some cases are only now being laboriously determined. The main difficulty in determining the creep properties of steels is that the tests, to be of any real value, take a fantastically long time. It may well not be possible to forecast how a steel will behave for 10 years under certain temperature and stress conditions without, in fact, subjecting it to such conditions for 10 years. This has led to even further assumptions regarding the expected long-time behavior of a steel deduced from relatively short-time creep tests.

The problem is very different from that facing the designer of jet engines, for example, which also require creep-resisting steel. Such engines have a much shorter life than steam power plant, a few thousand hours being all that is required. Consequently, the materials for them can be tested at working stress and working temperature, and the results obtained from tests of one or two thousand hours' duration will give all the information required for subsequent design. Unfortunately, users of steam pipes cannot wait the corresponding length of time for their test results, or even for the final assessment to be made of the mass of information already available. They must design their steam pipes here and now for the projected high-temperature power stations to be erected in the next few years. It remains, therefore, to consider now some rational basis for such design, and it is suggested that until very considerably more is known regarding the materials and their long-time be-

havior, the following method based on a rational development from first principles may well provide a reliable basis for design requirements for some years to come.

First, consider the basis at present used for power stations using mild-steel pipes at temperatures up to 900 deg. F., namely, British Standard 806. At low temperatures the stress in a pipe under internal pressure is given to a sufficient degree of accuracy by the use of Barlow's formula, namely:

$$S = \frac{P\,D}{2\,t},$$

where P = internal pressure; D = outside diameter; and t = thickness. This assumes that elastic conditions apply and B.S. 806 assumes that the stresses employed, at any rate up to about 850 deg. F., are sufficiently low to prevent any appreciable creep taking place. It is customary to add a small constant thickness to the value obtained from Barlow's formula (for example, 0.04 in.). The thickness obtained by such a formula in any case will have to have added to it allowances to cover commercial tolerances, but for the purpose of discussion here, this need not be given further consideration, since it will apply whatever the method of obtaining the calculated minimum thickness. B.S. 806 has proved a satisfactory guide to the required thickness for steam pipes in mild steel but does not, as yet, extend to temperatures such as 1,050 deg. F., for the power stations which are now under construction.

When a steel is subjected to a stress at high temperature so that it creeps appreciably, the distribution of stress which was present under the initial elastic conditions becomes modified, the stresses tending to equalize themselves, provided that the material is sufficiently ductile for such equalization to take place without fracture. Not all high-temperature steels are, in fact, sufficiently ductile, some ferritic steels, and perhaps others, permitting only a small amount of elongation to take place before fracture occurs. Such steels are unsuitable for high-temperature service, and the following assumes that sufficiently ductile steels, say those capable of extending at least 10 per cent. before fracture, are employed. In the initial elastic condition the stresses in the wall of a pipe under internal pressure consist of a hoop tensile stress which is a maximum on the inside surface and a minimum on the outside, a longitudinal tensile stress substantially uniform across the thicknes of the pipe, and a radial compressive stress which is a maximum on the inside wall and zero at the outside. There are many theories as to the method of combining these stresses, but none is universally accepted. The difference between them, however, is not great, and as previously mentioned, a close approximation to the combined stress under these conditions is provided by Barlow's formula.

As soon as creep starts, however, there will be a tendency for the hoop stress to equalize itself across the thickness and to become equal to the thin cylinder stress $\frac{P\,d}{2\,t}$, where d = bore. There is no need to be seriously concerned with theories which purport to determine the combined stress under creep conditions, since in fact the amount of creep depends upon the stress raised to such a high power that virtually all the creep will take place in the direction of the major stress. A typical example in the case of pipework under internal pressure would be that the creep in the circumferential direction (due to the hoop stress) might be 30 or 40 times as great as that longitudinally. It is even stated by some writers that no longitudinal creep takes place at all. Under creep conditions, therefore, when consider-

ing strength under internal pressure, only hoop stress need be taken into account. Thus, at the beginning of the life of the pipe the stress will be that given by the Barlow formula and at the end of its life, after creep, the stress will be that given by the thin cylinder formula. It remains to determine how much of the life of the pipe occurs before the Barlow stress has been reduced substantially to the thin-cylinder stress.

Equalization of stress requires only a small fraction of 1 per cent. extension, and on the usually assumed basis of 1 or more per cent. extension in the life of the pipe, such equalization time must represent only a small part of the total life. For the effective average stress during the life to be even a few per cent. above the thin-cylinder stress it would be necessary for the equalization time to be as long as a quarter of the life of the pipe, depending among other things upon the t/D ratio of the pipe concerned. It is suggested that a difference of a few per cent. is so small as not to warrant any departure from the thin-cylinder formula, and, in fact, this equalization is likely to be effectively complete quite early in the life of the plant. For such pipes, known to creep appreciably during their life, therefore, the thin-cylinder formula should form the basis for thickness calculation.

The next question is the stress which should be used in this formula. It has been customary, in the past, to consider as excessive any stresses which cause more than, say, 1 per cent, extension in 100,000 hours, and it is generally considered reasonable to make such stresses the limit, provided that they do not at the same time approach too closely the stress to cause rupture in 100,000 hours. This idea that a definite percentage of creep is detrimental has arisen from cases in which dimensional stability is important. For example, bolted connections may only be permitted a very small amount of relaxation. It does not, however, apply to pipework in which relatively large dimensional changes, say 2 or 3 per cent. in 25 years, would not be serious *provided* that fracture of the material did not occur. It is, in fact, failure rather than dimensional change which is the important point in pipework and it is suggested that the basis for design stresses should be the creep rupture strength of the material. This is known with some degree of accuracy for many of the steels involved, but it is important to base calculations on true minimum values.

It is usually assumed that 100,000 hours is a suitable life for estimating the stress to cause rupture. Hardly any tests have been carried out for such a length of time (11.3 years), and even these few only represent about half the expected life of power-station pipework. Extrapolation to 100,000 hours is difficult enough, but it is even more difficult to extrapolate beyond this point. Nevertheless, in the absence of actual test results, such extrapolation must be made. If it were known that, at a given stress, failure would occur exactly in 25 years, such a stress might be used in the formula, but obviously there is no such certainty and some factor of safety on this life must be allowed. There seems evidence that a stress of 80 per cent. of that which causes rupture in 100,000 hours would not cause rupture until about 300,000 hours, but a further factor of safety should be allowed on this 80 per cent. stress, and it is suggested that 60 per cent. of the best estimate of the minimum stress to cause rupture in 100,000 hours be used as a basis. This is not greatly different from the basis which the American Boiler Code uses for the high-temperature end of its stress curves. This percentage of the creep rupture stress is admittedly only an estimate, but it is hoped that it is also an intelligent esti-

mate. With such a stress, even if it should prove that the stress-rupture relationship has been slightly overestimated owing to insufficient data, it seems unlikely that any actual failure would occur in the life of the pipework, though there will, of course, be an increase in the diameter of the pipe. In the case of each steel under consideration, it would be necessary to check that this did not involve excessive deformation for the purpose for which the pipe is to be used. There would, however, be no significant alteration to its length.

The addition of the constant 0.04 in. (in B.S. 806), in the past, has been opposed by some who contend that, in fact, there is no corrosion in mild-steel steam pipes, quite negligible erosion, and nothing else which causes wastage of the pipe. In the case of ferritic steels at temperatures up to 1,050 deg. F., however, scaling is a factor which must be taken into consideration, and although the data are somewhat scanty, it seems probable that no allowance need be made at temperatures below 1,000 deg. F., though a constant may have to be introduced for higher temperatures.

In the case of mild steel, since it may be used at any temperature between room temperature and the maximum for which it is permissible (900 deg. F.), stresses for all intermediate temperatures must be laid down and are, in fact, so laid down in B.S. 806. It is unnecessary, however, to lay down stresses at all temperatures for the higher-temperature steels, since, in fact, they are not used at the temperatures between, room temperature and some quite high value depending upon economic considerations. As far as the low-temperature end is concerned, however, it is necessary to have some permissible stress at room temperature, since calculations of cold pull stresses in pipework need to take such temperatures into account. No difficulty is involved here, since the customary value of a quarter of the tensile strength at room temperature is a satisfactory basis. What can be considered suitable temperature ranges for different materials are given in Table I. These ranges are not very clear cut and may overlap somewhat more both upwards and downwards, but the last two ranges undoubtedly involve appreciable creep and should be calculated on the above basis.

TABLE I.

Temperature Range	Material
Up to 900 deg. F	Mild steel.
850 deg. F. to 975 deg. F.	Ferritic steels having 1 per cent. chromium content, with molybdenum and other additions.
950 deg. F. to 1,050 deg. F.	Ferritic steels having 2 to 3 per cent. chromium, with molybdenum and other additions.
1,050 deg. F. to 1,200 deg. F.	Austenitic steels.

The proposals contained in this article may be summarized as follows:

(*a*) A new formula and new stresses are required for pipes which creep appreciably during their working life.

(*b*) Owing to the relatively rapid equalization of stress across the thickness of the pipe, the stress falls from that given by Barlow's formula for elastic conditions to that given by the thin-cylinder formula.

(*c*) The proportion of the total life of such steam pipework which is spent under the higher Barlow's stresses is so small that, in fact, the thin-cylinder stresses can be used as representative stresses throughout the whole life of the pipework.

(*d*) Since, within limits, appreciable creep can be permitted to occur in a pipe, it is the stress-rupture condition which is all-important in the life of the pipework.

(*e*) It is essential that the steel used shall show appreciable elongation be-

fore rupture takes place under very long-time test conditions.

(*f*) In the case of ferritic steels at temperatures from 1,000 deg. to 1,050 deg. F. some allowance must be made for scaling.

(*g*) The minimum thickness should be derived from the following equation which is, in fact, the thin-cylinder formula:

$$t = \frac{P\,D}{2\,(S + P)}$$

where P = pressure; D = outside diameter; and S = permissible stress (60 per cent. of the minimum to cause rupture in 100,000 hours at the design temperature). For ferritic steels at temperatures over 1,000 deg. F. a small constant addition must be made to the value of "*t*" to allow for scaling.

It must be remembered that the final question regarding the use of all these suggestions and formulæ is "Are the resultant tubes of the right thickness?" The answer to this is not simple, since so few data on the actual use of these materials are available. What little information there is comes largely from the United States where these materials have been in use for some years. It is interesting to note, therefore, that thicknesses obtained by the methods outlined above are not greatly different from those which have given satisfactory service in that country.

OPTICAL MARKING-OFF SYSTEM FOR PLATES AND SECTIONS IN SHIPBUILDING

ACKNOWLEDGEMENT

This article, published in the October 30, 1953 issue of "Engineering," is an abridged version of a paper read at the Autumn meeting of the Institution of Naval Architects in Holland on 15 September, 1953. The author is Ir. J. H. Krietemeijer, Chief Naval Architect, Royal Company "de Schelde," Ltd., Shipbuilding and Engineering, Flushing, Netherlands.

THE author, who is in charge of the re-organization of the shipyard of the Koninklijke Maatschappij "de Schelde" Limited, at Flushing, Netherlands, has appreciated the possibilities of increased production that could be gained by applying the optical method in his plans for the lay-out of the new yard. He has called the method "Optaf," an abbreviation of the Dutch words "Optisch afschrijven," which means 'optical marking-off." An important product in shipbuilding is the steel hull, forming the base for all installations and fitting-out and eventually being finished as a complete ship. Depending upon the type of ship the work on the steel hull is a more or less important part of the total labor involved. Certainly the building berths for the steelhulls require large investment and occupy the largest area of the total yard. It must therefore be important to save space and cost on this side of the business.

The steel hull consists of smaller parts built up of plates and sections which are either riveted or welded together. In welded ships these parts are assembled in the welding sheds and the thousands of plates and sections and other small parts must be machined in the platers' shops. In most yards all plates and sections must be marked-off accurately before they are machined and given their eventual form by burning, shearing, planing, bending, pressing, etc. This marking-off must be done by platers of high skill. They normally occupy a considerable area in the plater's shop for their marking-off tables. In several countries it is difficult to get the highly-skilled workmen for this type of work, and it is of great importance to look for methods that diminish the expensive labor involved in marking-off.

During the last world war such a method was developed by Mr. Joh. Kriepke at the yard of Schichau, Elbing, Germany, in close co-operation with the optical works of Dr. Böger at Hamburg. The application in the yard to building destroyers showed

remarkable results. After the war the method was improved, and about 1949 it was introduced in one yard in Germany, one yard in Belgium and one yard in Sweden. After 1949 the apparatus was slightly improved and at present several yards are using it. The camera and projecting apparatus are fabricated by the two German firms "Lumoprint Böger K.G." and "Gesellschaft für Anzeichen Geräte" (G.A.G.), both at Hamburg.

THE USUAL MARKING-OFF METHOD

To show clearly the advantages it is necessary to give a description of the usual method in shipyards. After having obtained an order for the building of a ship two important things must be done. Firstly, making designs and working drawings; secondly, ordering all necessary materials. With regard to the new marking-off method the working drawings for the steel hull and the steel specification are of importance. After finishing the design of the lines, all measurements are taken from it and put in a list for the fore and aft parts of the ship. All particulars are thus collected for the use of the workmen who prepare the scrive-board in the yard on which all lines are drawn to full scale. Not only the form of the frames, but also particulars of form and dimensions of seams, situation of butts for welding or riveting, double bottom, margin plates, deck stringers, bilge keel, etc., are drawn on the scrive-board. Small errors in the measurements from the body lines plan drawing are eliminated by fairing longitudinal sections full size.

From this body plan on the scrive-board all necessary dimensions and particulars can be taken for giving the correct shape to plates and sections. All the working drawings of the steel hull must be delivered to the workshops. The principal drawings are shell plating, double bottoms, bulkheads, decks and superstructures. These drawings do not give in detail the measurements for all smaller parts, i.e., plates and sections, but they are more or less schemes with a description of the fabrication. The platers must read this scheme and take the actual measurements from the scrive-board. Normal practice is that highly skilled workmen make full-scale molds of wood, thin strip-iron or thick oil-paper for the templates or patterns. Usually other skilled workmen use these molds and mark the plates. As these templates are full scale, a lot of space, material and man-power must be used. The work on the large plates cannot be done by one man, and apprentices are added to the platers.

OPTICAL METHOD OF MARKING-OFF PLATES

The optical method depends upon the vertical projection of the lines on the plate from a projector placed in the roof of the platers' shop. These lines are on a lantern slide of 3 : 54 in. by 4 : 74 in. in the projector. The lantern slide is a photograph on a glass negative of a 1 : 10 or 1 : 5 scale drawing of the plate. The scale depends upon the size of the ship. These drawings are thus the 1 : 10 or 1 : 5 scale molds. Photographed to scale 1 : 10 they form glass slides which can be easily stored and eventually duplicated. These "glass molds" are about scale 1 : 100 for linear and scale 1 : 10,000 for area

measurement. The actual tracing of the projected lines on the plate does not require great skill and may be done by unskilled men under supervision of one experienced man.

DRAWING OFFICE

For a shipyard employing, say, 1,000 men, the number of draftsmen in the drawing office for optical marking-off is 6 to 8. Normally, they are the younger but experienced men from the former mold-loft and some highly skilled platers. A re-education of a few months is sufficient to teach them the special drawing technique and to accustom them to the psychological and physical circumstances which differ from their former surroundings. One foreman of the mold-loft may be appointed leader of the team. Principally the same work is done as formerly in the mold-loft, but on a smaller scale with fine drawing methods and the greatest accuracy. The small scrive-board is of plywood coated with filling and painted dead white or light green. Sometimes painted aluminum plate of 0.06 in. thickness is used. A few shipyards use drawing paper of special quality, pasted on an aluminum plate. The boards are divided into one foreship and one aftership part. The dimensions depend upon the ship dimensions. For bigger ships and scale 1 : 10 two boards of, say, 6 ft. 6 in. by 4 ft. are used for one ship.

An advantage is that a series of such scrive-boards may take several ships and occupy only a small space, whereas in the old mold-loft sometimes the body plans of two or three ships were traced over each other for lack of floor space. The lines are faired on a larger table of about 10 ft. by 5 ft. This table replaces the former mold-loft floor. The frame lines on the scrive-boards have a thickness of about 0.004 in. when drawn to scale 1 : 10 and of about 0.008 in. when drawn to scale 1 : 5.

The draftsmen use special tools and wear a pair of magnifying glasses fitted so that they can look through the glasses or along the underside of them. The former wooden templates are now replaced by drawings to scale 1 : 10 or 1 : 5. They are drawn on high-quality drawing-paper or, better, on Kodatrace drawing-film. All marks formerly traced on the templates and steel plates are taken up in the drawings. Mostly small rubber stamps are used for the marks and the characters. Port and starboard plates are drawn on one side only. The normal and reversed writing can be done by special stencils. For shell plates, deck plates, bulkhead plates, etc., two different methods may be used: (*a*) drawing all plates separately; (*b*) drawing several plates together, i.e., parts of decks, shell plating, or complete bulkheads. In the first case all plates are photographed from the different drawings. In the second case all plates are photographed one by one from one drawing. The last method has the advantage that all marks for rivets in seams and butts of the adjoining plates fit exactly. Slight mistakes in the spacing of the rivets are thus projected on both adjoining plates. Both sides of the drawings are photographed. It is not possible to reverse the slide. The thickness of the glass causes a remarkable aberration when projecting the image. It is obvious that slight shrinkage of the paper and film drawings caused by changing atmospheric conditions in the drawing office will result in consider-

able errors in the projected plate. Slight deformation of the emulsion on the glass negative will probably occur. A very simple solution will ensure a proper marking-off and guarantee the necessary accuracy.

ADJUSTING MARKS

These marks are indispensable in the optical tracing system. When starting the drawing these marks are laid down first. Immediately after them the outlines of the figure are drawn. After these precautions a slight deformation in the paper has no influence on the accuracy of the full-scale projected image and of the finished plate. The spacing of the adjusting marks is 5 or 10 cm., corresponding with 50 or 100 cm. on full scale. When projecting the lines on the plate these marks are brought in line with the marks on a steel or copper gage. By using special gages when preparing the drawings it is possible to deal with the expected shrinkage of the plates caused by the welding of stiffeners. After being finished the drawings are photographed.

OPTICAL MARKING-OFF EQUIPMENT

The marking-off apparatus consists of a projector incorporating a powerful arc lamp or mercury-vapor lamp. The projector is rigidly mounted in the roof of the platers' shop above the marking-off table. The height of the fixing point above the surface of the marking-off table depends upon the maximum dimensions of the plate. A special set of lenses enlarges the image from 75 to 100 times, thus projecting the image without distortion on the plate. The projector is adjusted for definition during assembly and once adjusted requires no further attention. It is possible to move the set of lenses with the negative case up and down within a range of 20 in. This permits compensation for differences in plate thicknesses and the adjustment of the image on the plate to the exact marks by comparison with the gage. The negative holder can be moved horizontally in two directions and can also be turned in its own plane. All these movements are effected by the man at the marking-off table by means of an automatic push-button system.

The arc lamp is provided with an automatic carbon feed. A concave mirror behind the arc and another mirror reflecting the light beam downwards, as well as a double condenser, produce an equally distributed light on the table. The heat intensity of the beam is very high and it is necessary to cool the condenser, the negative holder and the optical elements by compressed air. The light intensity of the projected image is such that it is possible to work without completely darkening the marking-off space.

The newest developments are fitted to the apparatus delivered to the author's firm. The two projectors were supplied by the Gesellschaft für Anzeichen Geräte, at Hamburg, and are fitted with high-pressure water-cooled mercury-vapor lamps. In addition, the negative holders can take a set of negatives which can be turned from below. With this equipment it is not necessary to have a man permanently in the projector cabin on the roof. The older arc lamps require a man constantly attending to the apparatus and replacing the carbons. All control can

thus be done from below by remote control. Only for filling the negative case is it necessary for a man to ascend two or three times a day. Aberrations inherent in lenses of optical systems are reduced to acceptable proportions by perfection of manufacture. The acceptable minimum, however, renders it necessary to have a slight camber in the marking table. This camber is about 1 : 5 in. in a length of 10 m. and is adjusted for definition during assembly.

MARKING-OFF PLATES

The projected lines have a thickness of 1.0 to 1.5 mm. and are rather sharp. The plater who marks the plate has no difficulty with his own shadow after short practice. The marking-off can easily be done by unskilled laborers. The men use a hammer and center-punch, while instructions and other marks are written with white paint. After the marking of the plates normal production follows and is practically uninfluenced by the method.

BENDING FRAMES

It is not possible to project the lines of frame curvatures on the bending slab as this is flat and a slight camber should be necessary. Normal practice is that series of frames are drawn together and, by projecting them, molds are made for use on the bending slab and for marking. A few shipyards still use a scrive-board near the bending slab on which the body plan or part of it is transferred. Most yards use their own method for applying the optical marking system in the preparing of frames, and in this branch new developments may be expected.

ADVANTAGES OF SYSTEM

The preparation of drawings requires less time than the preparation of mold-loft work and the production of templates in the mold-loft. The accuracy of the drawings is greater than that of the wooden templates. The draftsmen work in a quiet and clean room, and have a better general view of the small drawings than of more or less rough and large templates and dirty steel plates. If material is not available the preparatory work can be done in advance. Immediately after the arrival of the steel plates the marking-off, which takes only a short time, can start. Thus the workshops can concentrate more on the actual production. The drawing is projected in clear lines on the plate and a number of unskilled workers can mark-off the plate simultaneously. On an average, one shell plate with dimensions about 30 ft. by 8 ft. for a riveted ship can be traced by three unskilled men in 15 to 20 minutes.

Drawing a 1:10 scale paper mold with all necessary marks on it, thus forming the image which need only be projected to the plate, is more quickly done than making a template or marking directly on the steel plate. The same highly skilled craftsmen are required as in the mold-loft, but fewer of them. Only some of the skilled workmen formerly employed in the mold-loft are transferred to the drawing office. Unskilled workers and

helpers in the mold-loft can be transferred to other shops. Template production is practically no longer required. The tracing of the projected lines can be quickly done by a few unskilled men under supervision of one experienced foreman. The other skilled workmen can eventually be utilized more economically on the welding floors for assembly work. Wood for wooden templates is practically no longer required. Saving of steel, by reducing the waste, can be effected by accurately laying out the different parts of the available area of the plate on the 1 : 10 scale drawing. Mold-loft work becomes unnecessary to a great extent and is reduced to those components where special forms necessitate template work. Practically the whole area of the mold-loft floor can be used for other purposes. The storage of wooden templates is replaced by a small set of card cases containing the glass negatives. The necessary space for marking-off tables can be reduced considerably. The full-scale scrive-boards taking the body plans are generally dispensed with though some shipyards use them for special template work. Instead of these areas are the drawing office with adjacent photographic and dark rooms and the projecting space in the platers' shop. The glass negatives last for years and can be used again for repeat orders. Wooden templates have to be scrapped.

Often a group of shipyards have to build ships of the same design simultaneously. Uusually all working drawings are the same and are prepared by one of the yards. Each yard must repeat the same expensive preliminary work involved in mold-loft, scrive-board, templates, as well as part of the marking-off of the steel plates and sections. Nearly all this work can be omitted and replaced by preparing drawings and negatives in the leading yard.

Damaged ships' plates can be replaced by plates prepared in the repair yard with the aid of the optical system. The negatives are obtained from the building yard. This work can be done before the ship arrives at the repair yard. This advantage increases in importance where many yards use the optical method. Co-operation of several yards and a system of exchanging negatives on a large scale will enable repairs to be carried out at reduced cost and with considerable saving of time.

It is possible to use the drawings or the negatives first in the yard rate-fixing office. Using a simple table with a glass top and lamp below the drawtives to scale 1: 20 or 1: 25, all particulars of the work can be measured in detail, viz., lengths of edges to be prepared by shearing, planing, flame-cutting or welding, number of rivet holes, etc. There is less transport of large molds and less transport of steel material. All plates pass the optical marking tables only instead of the many tables formerly used in the platers' shop sometimes causing crane labor congestion.

PRACTICAL APPLICATIONS

Several yards are employing the optical system, of which the most important are given in Table I. Several other yards in Finland, Sweden, Norway, Germany, Africa and Japan, not mentioned in the table, have adopted the system or are about to do so in the near future. Most shipyards had their own reasons for applying the system. One typical example is the yard of Jos. Boel at Temsche, Belgium. From this yard were ordered three

Shipyard.	Town.	Country.	Number of Projectors.
Götaverken	Gothenburg	Sweden	6
Uddevalla	Uddevalla	Sweden	3
Chantiers de Normandie	Rouen	France	—
Stülcken	Hamburg	Germany	2
Howaldtswerke	Kiel	Germany	3
Burmeister Wain	Copenhagen	Denmark	4
Aalborg Vaerft	Aalborg	Denmark	1
Jos. Boel	Temsche	Belgium	1
"de Schelde" yard	Flushing	Netherlands	2
L. Smit	Kindedijk	Netherlands	1
August Pahl	Hamburg	Germany	1

TABLE I.—*Important Shipyards Using the Optical Marking-Off Method.*

Rhine tugboats of 4,000 brake horsepower, named Uri, Schwyz and Unterwalden. They were identical and built in 1939, 1946 and 1949, respectively. Three times the same full-scale scrive-boards were prepared, and three times all mold-loft work had to be repeated and all plates had to be marked. If the optical system had been available all glass negatives for the first ship could have been used for the second and third ships. In combination with the standard plates used in this particular yard the work could have been started immediately after obtaining the order, thus saving cost and shortening delivery time. The yard management regarded this as one of the strongest arguments for procuring the optical equipment in 1949.

OPTICAL SYSTEM IN THE "DE SCHELDE" YARD

In preparing plans for a new layout of the "de Schelde" yard the author was aware of the advantages of the method and could fully utilize it. The problems encountered in the old yard layout were mostly of handling and routing material. The yard was founded in 1875 and gradually expanded in an easterly direction on the north and south banks of the narrow dock. Formerly used as a yard for riveted ships, it could be typified as reasonably efficient, but when the prefabrication methods of modern shipbuilding in welded constructions were introduced the lack of pre-assembly areas and intermediate storage areas for finished units was becoming serious. A new platers' shop, the re-arrangement of existing and dismantling of other shops were necessary to obtain a layout as efficient as possible in the prevailing circumstances. As the existing mold-loft and scrive-board were old and had to be removed, the optical system offered an opportunity to eliminate them. In addition, the space formerly occupied by the marking-off tables could be utilized for machines, so that the old platers' shop with mold-loft could be removed.

The drawing office for optical marking was not combined with the construction drawing office. Though a combined drawing office has certain advantages, this problem must be studied in the light of the existing relation between the designing and yard departments. It is very useful to have close co-operation between the workshops and the optical drawing office, but it is still necessary to have close co-operation between the optical drawing office and the construction department. As a matter of fact, the de Schelde yard decided to start the optical drawing office in the yard's office, not combined with the construction drawing office. Fig. 1 shows a plan of the drawing office for optical marking in the de Schelde yard, Flushing. The de Schelde yard started with two projectors. A comparison between the areas in the old and new yard layout is given in Table II and the saving of space in the platers' shop is shown in Table III.

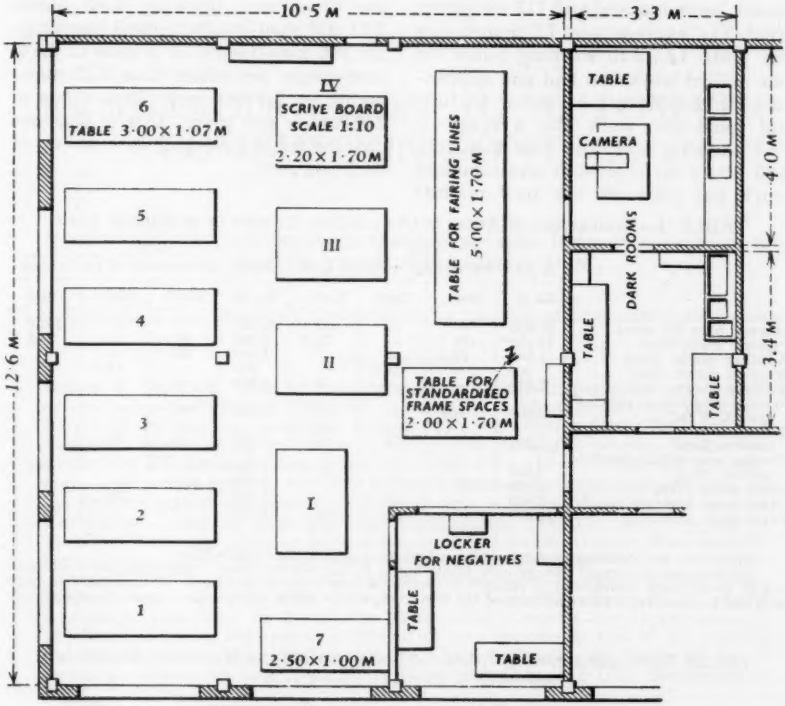


Figure 1. Drawing Office for Optical Marking Off

TIME SAVING

Several time studies were made for comparison. The saving in time depends on the type of plate to be marked. For two plates of a shell unit marked by one skilled man and one apprentice the times were observed and results given are below. The calculated times for marking with the optical method for the same plates and with two unskilled men are also given.

The total time per plate in the old method is 3.86 hours. The total calculated time per plate in the new method is 0.72 hour, i.e., only 18.6 per cent of the time with the old method. The preliminary work is not included, namely, the mold-loft and template work in the old method and the making of the drawings and negatives in the new method. An average of five different deck plates and shell plates for a ship of complicated construction and for the plate marking-off only is: old method, with one skilled and one unskilled man, 2.02 hours; new method, with two unskilled men, 0.625 hour, or only 21.4 per cent of the old method.

For a cargo ship of 315 × 49.2 × 23 ft., 398 shell plates (riveted frames and

seams, were marked and 112 templates used. The average was 7.5 man-hours per plate, i.e., 3.75 working hours for one skilled workman and one apprentice, mold-loft work excluded. Including mold-loft work the average is 7.65 working hours for two men, i.e., 3.90 hours for mold-loft and template work per plate. In the new method the times are: drawing shell plates 1.10, 930 man-hours; optical marking-off, 596 man-hours; or a total of 1,526 man-hours per plate; thus 5.12 man-hours, or, for two men, an average of 2.56 hours per plate. This is 33.5 per cent. of the old method, or a saving of 66:5 per cent.

TABLE II.—COMPARISON OF AREAS IN OLD AND NEW LAYOUT OF DE SCHELDE YARD.

	Old.				New.			
	Area.	Percentage of berth area.			Area.	Percentage of berth area.		
	Sq.M.	West.	East.	Total.	Sq. M.	West.	East.	Total.
Storage area for steel	20,000	—	—	147	20,000	—	—	147.0
Platers' shop, total	10,450*	128	—	76.7	7 000	86	—	51.4
Welding sheds, West	1,100	13.5	—	—	4,000	49	—	—
Welding sheds, East	900	—	16.5	—	900	—	16.5	—
Welding sheds, total	2,000	—	—	14.7	4,900	—	—	36
Storage area within reach of cranes, West	2,600	31.9	—	—	6,530	80	—	—
Storage area within reach of cranes, East	1,200†	—	22	—	1.200	—	22	—
Storage area within reach of cranes, total	3.800	—	—	27.9	7.730	—	—	56.7
Berth area, West	8,160	100	—	—	8 160	100	—	—
Berth area, East	5.470	—	100	—	5.470	—	100	—
Berth area, total	13,630	—	—	100	13.630	—	—	100

* Mold-loft not included as this is on top of machining shop (see Table III).

† This relatively small storage area under cover in the welding shop is sufficient for the building of naval craft which mostly remain for rather a long time on the berth. If necessary storage area can be reserved to the east side of the dry dock, which space is normally in use for repair jobs.

TABLE III.—COMPARISON OF AREAS FOR MARKING-OFF AND MACHINING PLATES AND SECTIONS IN OLD AND NEW LAYOUT.

	Old Layout.			New Layout.		Saving.	
	Area, Sq. M.	Per Cent. of Platers' Shop	Per Cent. of Total Area.	Area, Sq. M.	Per Cent.	Area, Sq. M.	Per Cent.
Scrive-boards	800	7.65	6.06	430	6.14	370	46.2
Mold-loft	2.750	—	20 85	—	—	2,750	100
Marking-off tables	3,000	28.70	22.75	—	—	2,640	88
Bending blocks	500	4.79	3.79	500	7.13	—	—
Optical drawing office	—	—	—	150	2.13	—	—
Projecting space	—	—	—	210	3.00	—	—
Machining shop	6,150	58.86	46.55	5 710	81.60	440	7.15
Platers' shop total—(exclusive of mold-loft as in old layout this is over the machine shop)	10,450	100.00	—	7,000	100.00	3,450	33.00
Total working area, mold-loft included	13.200	—	100.00	7,000	100.00	6,200	47.00

Conclusion—The purpose of this paper is to make known the optical marking-off system in wider shipbuilding circles. It is an interesting method and adds much to the improvement of shipbuilding technique, workshop conditions and efficiency in shipyards. Especially for the Netherland shipbuilding industry, which in the first quarter of 1953 took the fourth place in known world shipbuilding, it is of importance in exploiting the advantages of new methods for increasing shipbuilding output figures.

AN INTRODUCTION TO AUTOMATIC COMBUSTION CONTROL

CHIEF MACHINIST JOSEPH E. SCHIRMER, USN
CHIEF BOILERMAKER JOHN GRANDPRE, USN

THE AUTHORS

JOSEPH E. SCHIRMER, born in Baltimore and educated in parochial, public and private schools. Employed 1934-1942 as machinist, toolmaker and tool engineer. Part-time lecturer in vocational schools. Entered regular Navy 1942, serving mostly in repair ships, submarine tenders and floating drydocks. Senior Instructor at US Naval Schools, Boilermen, 1950-1953 where his interest in automatic combustion controls was first fathered. Attended factory courses at two of the leading control manufacturer's. Present duty is Boiler Officer aboard the new Task Fleet Command ship, the USS Northampton (ECLCI) which is one of the first combatant ships to have automatic combustion controls. Permanently commissioned Chief Warrant Officer in the regular Navy in 1944.

JOHN GRANDPRE, born in South Dakota and educated in public schools there. Entered regular Navy in 1940 serving mostly in battleships, cruisers and attack transports. Instructor in Automatic Combustion Controls for three years at US Naval Schools, Boilermen. Attended factory courses at two of the leading control manufacturer's. Present duty is Chief Boilermen in charge of No. 1 fireroom aboard the new Task Fleet Command Ship, the USS Northampton (ECLC1).

Automatic combustion control equipment as applied in naval engineering installations, varies in types and designs; and no attempt will be made in this paper to describe the operating principles of any one particular type of control system manufactured by any one company; but rather to explain the basic principles involved with the majority of types of automatic combustion equipment.

The usage of automatic controls is justified naturally, if the advantages outweigh the disadvantages. In this vein the following advantages and disadvantages are given. While we agree there may be more pros and cons than listed; it is felt that for the purpose of this paper; these are sufficient for discussion.

Advantages:

1. Automatic controls insure the operation of a boiler to which they are applied in the event of a casualty to the related equipment which would require the attention of the operating personnel. Further, in the event of injury to the operating personnel during combat, the automatic controls ensures operation of the boiler which is one of the most important items during combat.
2. In modern boiler design, the in-

creased temperatures and pressures with a proportional decrease in boiler size; stable control of pressure, temperature, water level (feed flow) and combustion ratio is becoming increasingly more difficult to maintain thru hand firing alone. Automatic controls definitely helps to minimize this difficulty.

3. Where long periods of operation are necessary, as on combatant ships, automatic controls help to eliminate the errors which result from personnel fatigue; this resulting in far greater safety to personnel and equipment plus a more alert watch ready to respond to any demand as conditions warrant.

Disadvantages:

1. Specially trained personnel are required for operation and maintenance. It might be said here, that any good engineer with a normal basic background and operating experiences can learn, without too much difficulty, to operate and maintain any automatic control system.
2. Additional weight factor. However, recent design trends towards miniature controls and instrumentation should eventually eliminate this disadvantage.
3. Initial installation is costly. It can be stated here that it must be remembered that the savings in fuel and feedwater along with decreased maintenance costs, more than enough makes this disadvantage a very slight one.

Automatic controls are designed to control such variables as:

1. pressure
2. temperature
3. water level (feed flow)
4. combustion ratio (fuel-air ratio)

Many of the types of controls that have been developed may be readily adapted to any or all of the variables listed above.

For better understanding of this continuous process of automatic control, a list of definitions used in connection with it are listed:

Controlled Variable:

the variable which the automatic system is controlling the value of; eg: if the automatic system controls steam pressure in a boiler, then the STEAM PRESSURE is the controlled variable.

Controlling Variable:

the necessary elements imparted to the controlled variable to maintain it at some definite value; eg: if the automatic system holds steam pressure at a given value by varying the fuel-air ratio to the boiler; then the FUEL-AIR RATIO is the controlling variable.

Standard:

is the desired value of the controlled variable; eg: if the automatic system is set to control steam pressure at 600 psi, then the 600 psi is referred to as standard.

Proportional Band:

the deviation of the controlled variable that is necessary to vary the controlling variable from minimum to maximum range; eg: if a 15 psi steam pressure deviation is required to vary the oil and air flow over its full range, then 15 psi is the proportional band.

Power Drives:

the units which operate a mechanism for varying the controlling variable; eg: the diaphragm and spring of a valve are the power unit to operate the valve and control the flow through it. To control air to a furnace, the power drive which positions the damper and regulates air flow may also be a diaphragm spring-opposed drive or an air operated piston type of power drive.

From the definitions above, it can readily be seen that any automatic control system must have the following basic elements before it can be conceived and designed for operation.

1. A controlled variable that will vary.
2. Controlling variable which may be varied by the control system.
3. A device to measure the controlled variable and relay this value to a controller.
4. A controller which has an outside power source supplied to it, and which it proportions to the amount of the controlled variable deviation; then transmits this value to vary the controlling variable to bring the controller back to the desired value.
5. Power drives which move in accordance with the variations in the power sources to vary the controlling variable.
6. Transmission system to relay the power source to the power drives.

The requirements for an efficient automatic control system are but two: a. energy supply rate must equal energy demand rate, and b. energy supplied must be at a specific potential established by the demand.

Certain features of automatic control equipment remain basically the same regardless of the manufacturer's type, due to their specific purpose. One of the first steps in automatic control is to measure the controlled variable, and this is usually accomplished with some type of a sensitive element. This element may be any of the following, depending upon the nature of the controlled variable:

a. bourdon tube, bellows or helical coil which moves in accordance with a pressure change.
b. bellows or diaphragm which moves in accordance with a differential pressure change.
c. thermal tube which will expand and contract in accordance with a temperature change; or a resistance element which varies an electrical output due to temperature change.

Unfortunately, the allowed variations of the controlled variable in most cases is slight, and demand that the allowed movement of the sensitive element be sufficient to mechanically move the power drives and change the controlling variable to meet demand. Due to this fact, some outside power source must be introduced to accomplish this work. This power source may be either pneumatic, electrical or hydraulic. Variations of the power source (which as a final result, vary the con-

trolling variable over its full range), are controlled by the movement of the sensitive element; which is proportional to the variation in the controlled variable. The first action of an automatic control system is brought about by a change in the controlled variable which moves the sensitive element. This movement sets up a proportional impulse from the power source, which, moves the power drives and changes the controlling variable to bring the controlled variable back to its correct or desired value. A cycle, or in short, an automatic control system has been set up.

Where the allowed variations in the controlled variable are large enough, the movement of the sensitive element may be transferred mechanically to the power drives. An example of this type of control would be a thermo-mechanical feed water regulator.

To clarify the types of controls, it is best to first consider the type of variation in the controlling medium which is brought about by a change in the controlled variable. The following are some basic types of automatic controls:

Two-Position Control:

a system arranged to operate the controlling variable from opened to closed for small deviations in the controlling variable. The time to open is controlled by the load.

Proportional Control:

a system arranged to proportion the change in the controlling variable in accordance with the change in the controlled variable.

Floating Control:

a system arranged to employ a combination of 2 types of control. For a change in controlled variable, the system floats the controlling variable in order to bring the controlled variable back to standard. When the controlled variable is returned to standard, the controlling variable is stabilized; and maintains this rate, awaiting the next change in demand. While the controlling variable is in this stabilized condition, the controls are Proportional. The initial change is made by the Floating control and after this change has met the demand, it is held there by the Proportional control.

The above types of controls are not by far, all the types that are employed but for the purpose of simplicity in this paper, they are the only ones being considered. For the most, the above types of controls are generally employed by naval engineering installations, although many times they are not recognized as such. For example: the control of pressure in an air compressor receiver is typical of 2-Position control where the controlling variable, which is the supply of air from the compressor, is being supplied to the receiver or completely secured for a variation in the receiver between the two set limits. The pressure range between these two limits is the allowed variation in the controlled variable. Floating control by itself is not used too extensively; but a combination of Proportional and Floating control is

used quite extensively in the application of automatic controls to boilers.

One of the primary reasons for the research in the development of the different types of controls, was the use of automatic controls and feed water regulators for boilers. The ultimate objectives of any steam generating unit are: (a) to supply the necessary quantity of steam under specified conditions of pressure and temperature at the times required; and (b) to obtain the maximum efficiency. These objectives require the adjustment of the fuel-air delivery to the furnace in the proper ratio, as well as the regulation of furnace draft to remove the resulting products of combustion. Consideration must be given to some of the obstacles encountered in the control of boilers which automatic systems must be designed to compensate for.

The energy storage capacity of a boiler is the major factor in the system, and the effect of this energy storage during fluctuations in the controlled variable is determined by the amount of stored heat released and absorbed for a unit change in temperature, as compared with a steady ratio of heat supply. Further, energy storage can be classified into two main divisions: (a) demand side—the amount of steam in a boiler that a demand may be put upon, and (b) supply side —the amount of combustion available to control steam output. Temperatures and pressures stored in a system depend to a large degree on the size of the boiler.

Taking energy storage as a factor, the next step is to consider the amount of time it takes an automatic system to change the firing rate of a boiler to meet the change in demand. The amount of time involved depends on the magnitude of the lags encountered. Lags in all automatic control systems usually fall into the following categories:

Transfer Lag:

time required for an increase in combustion rate to produce the increased steam output due to the thermal resistance between firesides and watersides of a boiler.

Transportation Lag:

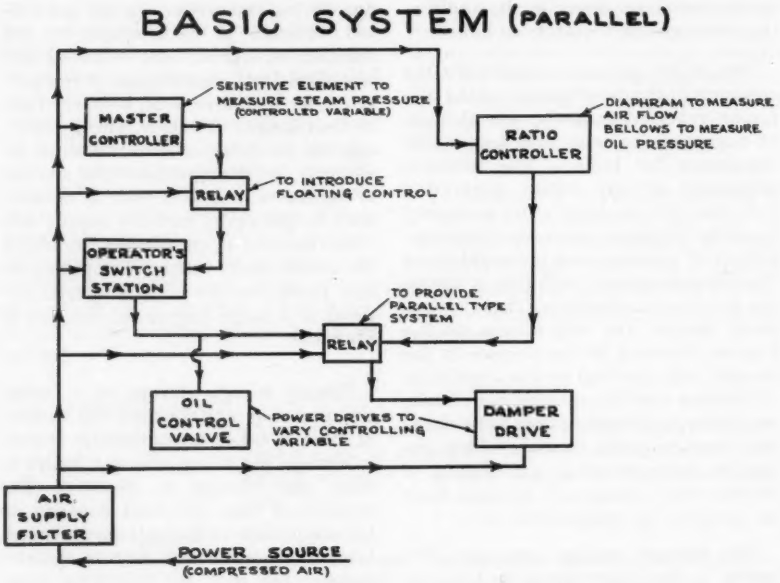
time required for a change in steam demand to reach the controller.

Controller Lag:

time required for the controller to send an impulse or change the firing rate of a boiler.

As a result of these lags, a tendency to temporarily either over-fire or under-fire a boiler is created each time the demand is changed. It is evident therefore, that the controls must be designed and adjusted to compensate for this over or under firing if efficiency and stability in operation is to be maintained. This is best accomplished by selecting the type of control to cope with an individual situation and adjusting the sensitivity of the controllers to obtain maximum stability.

As previously stated, automatic control systems are varied in design, but all must contain the following basic instruments in some form or other:



Master Controller:

this instrument contains the sensitive element for the measurement of the controlled variable, and develops a proportional impulse which it sends out to vary the controlling variable.

Operator's Switching Station:

an instrument to allow the operator to shift the controls from "automatic" to "manual" or to "hand" with minimum time delay in case of equipment failure, etc.

Power Drives:

a mechanism to vary the controlling variable in accordance with the impulse changes originating in the Master Controller.

Ratio Controller:

an instrument to measure either oil flow, air flow or both; and to develop an impulse to control either flow of oil or air. By accomplishing this, the ratio controller maintains a set ratio of the "elements of combustion." This set ratio is determined by the operator to compensate for the variation in sizes of sprayer plates used. Most

ratio controllers compensate for the variation in the number of burners used by automatically measuring the flow of air to the burner rather than the furnace or pressure casing alone.

Automatic combustion control systems are also referred to as being either series or parallel. If the elements of combustion are both increased or decreased by the Master Controller for a change in rate, and the Ratio Controller then re-positions the power drive which re-aligns either air or oil flow, the control is said to be a parallel type. However, if the Master Controller positions only one power drive, and e.g.: controls air flow, the Ratio Controller must measure air flow and develop an impulse relative to this measurement. The impulse from the Ratio Controller then positions the power drive to control oil flow. This control is then said to be series due to the fact that the "elements of combustion" enter the furnace in series.

In addition to the equipment listed above, most pneumatically operated automatic control systems are equipped with Relays. A Relay in this sense is an instrument which reproduces pneumatic pressures, and usually consists of from two to six chambers. Relays can be made to reproduce an average of the received impulses, the sum of the received impulses, the difference between two or more received impulses or the identical reproduction of a single received impulse. Depending on their particular use in the system, the purpose of a Relay is to add stability, flexibility or sensitivity to an automatic control system. Relays must be arranged to work in conjunction with the Controllers in the system, and to aid in the proportioning or controlling of an impulse. In the pneumatic control system where no Relays are used, this proportioning or controlling of an impulse must be accomplished in the controllers themselves.

To apply automatic combustion controls to an integral type superheater boiler (single furnace), the control system remains relatively basic. Steam pressure is the only factor measured through a single Master Controller, and the system develops a relative impulse to control combustion rate and to maintain the desired steam pressure. As a result of controlling combustion rate and maintaining the proper air-fuel ratio the desired superheater outlet temperature is readily maintained.

To apply automatic combustion controls to a separately fired superheater controlled boiler (divided furnace) is rather a complex problem, in that a near-perfect balance of the firing rates of both furnaces must be maintained at all load changes in order to prevent the controls from "hunting." In this application, two controlled variables, steam pressure and steam temperature are measured by two Master Controllers. One Master Controller measures steam pressure and develops an impulse relative to it to control the combustion rate of the saturated furnace; while the other Master controller measures steam temperature and develops an impulse relative to temperature change to control the combustion rate in the superheater furnace and maintain the desired steam temperature. The usual arrangement for an automatic combustion control system for this type of boiler is to allow the Master Controller, which measures steam pressure, to vary the combustion rate on both furnaces when a change in steam demand occurs. The Master Controller measuring steam temperature then restricts or corrects the superheater fur-

nace combustion rate to maintain desired temperature. To accomplish this, it is necessary to introduce several relays into the system that will permit the superheater furnace combustion rate to be changed in accordance with the impulse change originating in either of the two Master Controllers. In view of recent developments in naval boilers, and the experiences gained by the use of automatic combustion controls, it is believed by the authors that this type of boiler will eventually be eliminated.

Automatic combustion control equipment will give satisfactory and efficient control only if it is operated and maintained by properly trained personnel. In the maintenance and calibration of controls, manufacturer's instructions should be adhered to strictly, and common engineering sense applied. Tinkering with the controls should never be tolerated. Where possible, the control console or room should be locked when not in use. Maintenance is the key to efficiency.

In conclusion, the authors have seen and have helped to make operate, automatic combustion controls for naval boilers. They have witnessed the efficiency, flexibility, stability and economy of automatic controls. Where control systems are installed, operating personnel must be made aware of the advantages of the controls and realize that any control is only as good as the operator.

REFERENCES

1. Instrument and Control Manual for Operating Engineers by Feller, 1946 McGraw-Hill.
2. Automatic Feedback Control by Ahrendt & Taplin, 1952, McGraw-Hill.
3. Automatic Control Engineering by Smith, 1944, McGraw-Hill.
4. Theory of Servomechanisms by James Nichols & Phillips, 1950, McGraw-Hill.
5. Servomechanism Fundamentals by Lauer, Lesnick & Matson, 1947, McGraw-Hill.
6. Combustion Control by Skrotzki, Power Magazine. Dec. 1949.
7. Automatic Control Terms, ASME, June 1952, No. 52-SA-29.
8. Multiple Element Control Systems by Gorie, 1946 ASME No. 46-A-38.
9. Operation & Care of Boiler Control Systems, by Bailey Meter Co., 1943.
10. Selecting Automatic Control Equipment for Continuous Processes by Gorrie 1940, Bailey Meter Co.
11. Fundamentals of Automatic Control by Ross and White, Industry and Power Magazine, Sept. 1951.

STANDARDIZATION OF DIESEL-ELECTRIC POWER PACKS

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INTRODUCTION

The World's Market and Suggestions for Increasing the Demand. The rapid advance in the design and performance of high-speed internal-combustion engines of the Diesel type, resulting in relatively low initial cost and high working efficiency, has promoted an increasing demand for engine-driven electric generating sets. The demand would increase much more rapidly if there were readily available a standardized generator power pack or at least a kit of versatile components that could readily be assembled into complete power units.

Engine-makers already manufacture large numbers of standardized mechanical power packs, the design and construction of these being within their own province, but with electrical power packs not only other manufacturers but other techniques are involved. Therefore considerable attention must be given to the arrangement and to the design of the electrical end, also to the method of coupling both the rotor and the stator of the generator to the engine, and to the final assembly of the unit to permit the use of the complete set without undue vibration.

Possible World's Free Market for Alternators Alone. Alternators for internal-combustion engine drives are being produced in Great Britain at the rate of about 400,000 kVA. per annum in units of capacities lying between 5 and 500 kVA. This figure which is based on a specific or reference speed of 1,000 r.p.m., covers all machines manufactured for the services, for home, domestic, industrial and stand-by purposes. At least half is directly exported. Statistical information on "Electro-generating sets powered by Diesel engines produced in U.S.A." and exported during the past 5 years gives an average value of $21,000,000 per annum and the average number of sets corresponding to this value is 4,000. As these units are sold in the open market it is reasonable to estimate that their kVA. capacity will be similar to that of the

U.K. product which for the price in question would be approximately that of 60 kVA. at 1,000 r.p.m., making the total annual U.S.A. exports about 240,000 kVA. and the price per kVA. approximately $90. Other countries, such as Denmark and Sweden, not only produce similar sets for their own use but export them to Norway, Finland and the Commonwealth countries, in particular India. Similar conditions exist in Belgium, Germany, France and Italy; India being a good customer to most. In these circumstances it could be assumed that a further 160,000 kVA. is sold, making a free world total market of 800,000 kVA. which, at $21 per kVA., gives a total of $16,800,000 for alternators alone.

Possible World's Free Market for Complete Power Packs. The price per kVA. for the power pack will depend on how elaborate it is and on the speed of the prime mover. For a unit with the simplest type of switchgear, running at 1,000 r.p.m., the price per kVA. may be taken from the U.S. figures above to be about $90, making the free demand of the order of $70,000,000. Although this is already a very large market it is only in its infancy, for due to the demand for a better standard of living and better industrial services, more sources of electric power will be required. New uses will also contribute to this potential market.

Some Applications of Power Packs. Power packs may be regarded as falling in two broad classifications namely, those for continuous service and those for stand-by, peak-load or emergency services. Continuous service includes use for power and lighting in small towns and villages or on constructional operations, hatcheries, oil wells, mines, gravel pits, camps, farms, quarries, ships, and use by the armed forces. Stand-by or intermittent services are required in factories of all types, hospitals, hotels, bakeries, schools, large stores and offices, also Post Offices, radio and television stations and telephone exchanges.

These lists are not nearly complete but indicate a field of supply already wide enough to make standardization of several sizes of power pack an attractive proposition apart from provision against power cuts and supply failures. If, as one example, the light fails suddenly in a large store filled with people, apart from the resulting danger and inconvenience, a considerable amount of material may be lost. In such circumstances an emergency power source may be an economic asset and the complete realization of such possibilities will enlarge the demand for stand-by units very considerably.

Effect of Standardization in Increasing Demand. A standardized power pack must be simple and robust; compact and portable; and have spare parts that are readily available and simply assembled. Simplicity and robustness is necessary because internal-combustion engines, particularly of the Diesel type, have many vibration frequencies which can interfere with the wear and working of the more delicate parts of the equipment, particularly on the electrical side, Aiming at complete standardization, it would be desirable to have at least all basic parts of the packs designed for portability even if they were finally used as stationary plant: while to make standardization completely effective it will be necessary to have pertinent data available and in the hands of the users as well as in those of the sales organizers. It is almost unnecessary to stress the value of general standardization. A readily available standard power supply does in itself create demand and the quality, delivery, price and consistency of the product are favorably affected.

Engine. In the manufacture of electrical power packs, only high-speed

engines of the compression-ignition, solid-injection, 4-stroke type need be considered. Moreover, in the range now considered 4- or 6-pole generators are normal, so that only four engine speeds are required, namely, 1,500 and 1,000 r.p.m. for generating at 50 c/s and 1,800 and 1,200 for generating at 60 c/s. It would appear that the British output of 60-cycle generators is not great but engines between 80 and 100 h.p., almost equally divided between the speeds of 1,500 and 1,000 r.p.m. are now in very great demand for driving generators. Where both 50- and 60-cycle machines are required, a speed range of 1,500-1,800 r.p.m. is almost universally used for engines developing up to 80 h.p. Thus a range of powers from 20 to 150 h.p. running at 1,500-1,800 r.p.m. and another range running at 1,000-1,200 from 50 to 200 h.p. would cover all the requirements for standardized power packs. Such ranges are readily available, for it is the practice of many engine-makers to design their engines with a maximum number of cylinders and reduce the number for lower powers. A 6-cylinder unit may be arranged to develop 5/6 or 4/6 of the maximum power by reducing the cylinder numbers to 5 and 4 respectively, making available a large range of engine outputs while using the same cylinder size. Reasonably portable power packs can be manufactured with engines developing up to 200 h.p. at 1,000 r.p.m. There is generally no need to go beyond this power as greater outputs can be achieved economically by running two or more sets in parallel. Although the first cost of the paralleled plant may be slightly higher than the single larger unit and the efficiency slightly less, there are considerable advantages obtained in multiplying units, such as possibilities of lower light-load losses, greater portability, more effective spares and freeing of individual units for maintenance and overhaul. Finally, although actual supplies of suitable engines are available, standardization of such factors as mounting dimensions and bell housing size is of urgent importance, but as these details affect the driven generators, suitable standards in the electrical apparatus become of still greater urgency and importance.[1]

Generator Standardization. Many factors influence standardization of the generators, and the most important of these are, for A.C. generators:

(1) Revolving field or armature type.

(2) Versatility of generator design to comply with changes of voltage, frequency, speed and power factor.

(3) Method of voltage regulation.

(4) Suitability for paralleling.

(5) Number of phases.

(6) Method of cooling.

(7) Mechanical adaptation.

The frames of D.C. generators should be interchangeable with those of the A.C. generators of equivalent output.

So far as possible each of the above factors will be considered in the light of existing practice and the advantages to be gained in standardization by the use of a new form of generator.

Revolving Field Versus Revolving Armature Designs for A.C. Generators. Revolving field alternators, particularly of small and medium sizes have many advantages over revolving armature types and would be used to a much greater extent if the manufacturing costs were more nearly equal, a condition which, thanks to improved design, now exists. The principal advantages of revolving fields are as follows:

(*a*) They require only 2 slip-rings carrying D.C. of moderate values

against 4 slip-rings carrying A.C. sometimes of values greater than the capacities of single rings. The brush gear is simpler.

(*b*) Collection of A.C. is more difficult than of the D.C. under the same conditions and results in considerably more maintenance.

(*c*) The stationary armature windings make paralleling of the coils possible (without multiplying slip-rings), for instance, coupling for phase e.m.f. of half value.

(*d*) The revolving part of the generator is wound with a low voltage simple winding which will be standardized in similar sized machines having the same number of poles. For higher voltages the revolving armature design is impracticable because of trouble in insulating the conductors.

Conventional A.C. *Generators Controlled by Automatic Voltage Regulators* (*A.V.R.*). Conventional generators are usually designed with an inherent voltage regulation of 30 per cent. at 0.8 power factor, that is, when the full load is switched off the terminal voltage should not exceed 1.3 times the full load value when operating without automatic voltage regulators (A.V.R.s).[2]

If, with some saturation in the magnetic circuit, the design of a conventional generator were such that inherent regulation could be obtained with 1.7 m.m.f. units on the field at full load 0.8 power factor, at light load the same voltage would be obtained with 1 m.m.f. unit. The duty of the A.V.R. for level voltage would be to remove 0.7 m.m.f. unit from full to no load. Normal automatic voltage regulators do this reasonably well although their response is sluggish. Since the field is large relative to the load winding it is normally placed where there is most room for it to give the least loss. This is at the outer diameter so that revolving armature machines are usual in small sizes.

Improvements in A.C. *Generator for Standardization.* When, in the conventional machine the field magnetizing m.m.f. (that is, the m.m.f. at no load) is reduced drastically by reducing the air gap of the alternator, two limitations become apparent. Firstly, the range of field m.m.f. from no load to full load becomes too great for the normal exciter regulator system. Secondly, the magnetic effects of the load currents in the armature distort the wave-shape of the alternator voltage. The first limitation can be overcome by using an amplifying exciter with built-in regulating circuits,[3] and the second by distributing the field windings over a round field structure so that the field currents will oppose any tendency to field distortion. With these precautions the field ratios are as shown in Table I.

TABLE I

	Field m.m.f.				
	No load	Extra for full load, 0.8 power factor	Total full load, 0.8 power factor	Ratio of m.m.f. full load: no load	Field loss for same copper space
Conventional alternator	1.23	1	2	1.63:1	4
New alternator	0.25	1	1.17	4.7:1	1.37

The field m.m.f. ratio full load: no load has risen from 1.63:1 to 4.7:1 and is outwith normal A.V.R. control.

With the new arrangement the total field m.m.f. required is much less. As the field loss for the same copper space varies as the square of the m.m.f., the losses in the field become very much less (1.37:4) or, alternatively, for the same loss the field can be put into much less space. Rotating field machines down to very small sizes then become a possibility, giving the advantages listed above. In addition, the machine will be much smaller than the equivalent revolving field design. A possible disadvantage is that a failure of the regulating system may allow a dangerous rise in voltage of the system.

A regulating exciter, the Magnicon, designed by the Authors,[4] has been extensively applied in the above way and gives, in addition, closer regulation under static and (particularly) transient loads than the normal A.V.R. on conventional machines. In addition it has been used to limit the voltage if the control circuit breaks, and the short circuit current if a symmetrical short circuit occurs on the load side of the generator.

Improvements on D.C. *Generator Design which aid Standardization.* Direct current generators which develop equal outputs from the same frame sizes as the equivalent alternators can be economically made by using completely laminated field systems and compensating winding.[5] Salient poles are not required and the outside diameters of the generators frames can be reduced to the same overall dimensions as the equivalent A.C. generators. The fields are wound into slots as in the A.C. generator or induction motor. Compound windings are not required as sufficiently level volt-ampere characteristics for most purposes can be obtained by brush movement. If rigidly constant terminal voltages at widely different levels are required, exciters are used. Parallel operation between generators is maintained by using a link between the ends of the exciter compensating windings: this link does not carry more than 1 per cent. of the full-load current.

Many D.C. power packs for arc and other welding processes have been and are being manufactured,[5] but the electrical requirements are abnormal and often require the use of special generators and switchgear. It is not impossible, however, for these to be embraced within the fold of the standardized power pack by a broad consideration of all the special requirements. There is no great demand for D.C. packs for ordinary power purposes; at least 90 per cent of all present requirements are for A.C. polyphase generators for large, and single-phase for small units.

Switchgear Standardization. Standard switchgear should be mounted to limit the effects of engine vibration and should ensure mistake-proof handling of the electrical circuit.

The switchboard as a unit should be arranged to move on a damped flexible mounting, or the damping of the whole machine should be the best possible.

Switchgear should be as simple as possible consistent with good performance and built up of standard parts for which spares are readily obtainable.

The switchgear should be designed so that with the minimum of modification it should deal with changes of voltage, frequency, number of phases, the supply of D.C. circuits and paralleling of sets under all these conditions.

ENGINES

Basic Rating. British internal-combustion engines are rated in accordance with B.S. 649 (1949). Their output is affected by altitude above sea level, ambient or engine-room temperature, and the humidity of the atmosphere. The basic values of the above are 500 ft., 85°F. and a vapor pressure of 0.6 in. of mercury respectively and engines must run at their rated speed and develop their rated b.h.p. continuously for 12 hr.

Loss of Output due to Departure from Basic Conditions. For every 1,000 ft. altitude above 500 ft. and every 10°F. over 85°F. reduction in the rated b.h.p. of 4 and 2 per cent respectively must be made. The derating percentage due to humidity not only depends on the percentge humidity but also on the atmospheric temperature, and tables relating to these values are given in B.S. 649. Service specifications usually cover the widest limits in environmental conditions, altitudes up to 5,000 ft., temperatures up to 125°F. and humidity up to 100 per cent., but all these are not usually specified as occurring together for instance, temperature of 125° and 90° F. are occasionally specified at 500 and 5,000 ft. levels respectively, but a humidity of 50 per cent is seldom encountered at temperatures as high as 125°F.

Table II shows the derating percentages for the two extreme conditions.

TABLE II

		Derating per cent.		Derating per cent.
Altitude, ft.	500	0	5,000	18
Temperature, °F.	125	8	90	1
Humidity, per cent.	50	5.5	100	3.3
Totals, per cent.		13.5		22.3

Reduction in air density at high altitudes has a great effect on the value of the derating percentage because of the reduced weight of air per cylinder charge and less effective fan cooling. The generator also suffers in the latter cause to the extent of 1.5 per cent per 1,000 ft. from sea level for altitude above 3,300 ft.

Torque, Speed, and Specific Weight. Examination of published characteristic curves of various Diesel engine,[6,7] reveals the interesting fact that the torque which they develop remains approximately constant throughout a large speed range, and within this range the size, weight and (neglecting extremes) the cost of engines remains reasonably constant and independent of the speed. Published data also show that speed ranges greater than 2:1 are quite usual, in which the torque does not vary by more than about 5 per cent throughout the range.

An important figure in the design of engines and power machinery generally is the specific output, in engines the torque developed per lb. of material used, in electric generators per cu. in. of core volume. This figure is often loosely expressed in mechanical engineering as a reciprocal, that is, in lb. weight per h.p., without reference to the speed at which the h.p. is developed, whereas in electrical engineering when a comparison of plant

sizes or weights is required it is customary to express torque in kW. or h.p. per 1,000 r.p.m.

Comparison of Specific Torques of Engines and Dynamos. On several occasions the authors have commented "It is a curious coincidence that nature having provided two metals, copper and iron, used in the construction of the electric and magnetic circuits of dynamos, should also provide that the properties of these are such as to enable a close relationship to exist between the specific weights of those generators and the prime movers driving them. This relationship may not appear at first sight to be very close, but, nevertheless, there exist large low-speed prime movers driving generators of half their specific weight while at the other end of the scale there exist high-speed prime movers which are driving generators of double their specific weight." To estimate how close this relationship could be the specific weights of many makes of engines were calculated from published information[6,7] and compared with these obtained from a line of standard 1,000 r.p.m., 50-cycle alternators recently put into production. The full-line curve in Fig. 1, shows alternator weights per h.p. at 1,000 r.p.m., plotted as ordinates, on abscissae of h.p. at 1,000 r.p.m. The broken line, curve B, shows an average weight in lb. per h.p. at 1,000 r.p.m. estimated from the information given by 6 representative British manufacturers of 4-stroke industrial Diesel engines. The relevant engine weights were specified as total dry values including radiators, fans, air filters, starting gear and flywheels. Fig. 1 also shows the specific weights of a con-

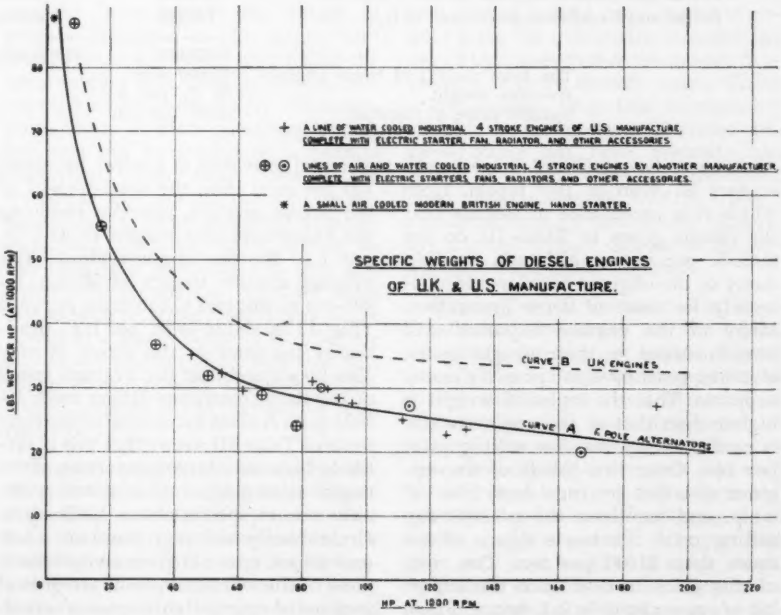

Figure 1

siderable number of engines of American manufacture and it will be observed that the specific weights of these engines correspond very closely to those of the alternators of corresponding output. In the case of air-cooled engines the agreement persists for outputs of under 10 h.p. at 1,000 r.p.m. and this provides a remarkable confirmation of the comments above.

Comparison of Specific Weights of British and American Engines. It appears that the specific weights of U.S. engines can, without much error, be taken as equal to those of the corresponding alternators and, that engines of British manufacture are relatively too heavy by 25 to 35 per cent. In the report of a visit to the United States in 1949 of a British productivity team representing the internal-combustion engine industry the following comments appear: "One of the most striking features of American practice is the tendency to use cheap materials; in particular cast iron is used on every possible occasion and light alloy is little used."[8] As some further evidence on this point, Table III gives details of the British exports of internal-combustion engines for 1952.

TABLE III

Type and power	b.h.p.	Value £
Diesel engines up to 50 h.p.	780,000	11,838,000
Diesel engines from 50 to 300 h.p.	334,000	4,429,000
Diesel engines over 300 h.p.	252,000	3,330,000
Petrol and paraffin engines up to 10 h.p.	175,000	1,935,000
Petrol and Paraffin engines over 10 h.p.	138,000	290,000
	1,679,000	21,822,000

The total weight of these engines =65,000 tons
Average weight =87 lb. per h.p.
Specific price of material =£337 per ton

A separate list of Diesel-driven generators is given in the report, from which it is reasonable to assume that the details given in Table III do not include generators, although possibly many of the engines listed would ultimately be used to drive generators. Many of the engines exported will have included in their weight gears, clutches, gearboxes and possibly heavy supports. That the included weight is higher than that of the engines alone is confirmed by the low selling price per ton. Over two-thirds of the engines detailed average less than 50 b.h.p. and for these the present-day selling price reaches a figure of not more than $1800 per ton. The ratio of this price to that from the export list is approximately 2:1, hence it may be reasonable to argue that the weight of metal exported is greater by about 100 per cent than the total weight of the actual engines, thereby reducing the export specific weight to 43.5 lb. per h.p. for the engines alone. The average specific weight of 50-h.p. 1,-000-r.p.m. engines taken from curve B (Fig. 1) is about 44 lb. per h.p., practically the same as the above. It may also be argued that the average speed of the listed machines differs from 1,-000 r.p.m. A close inspection of the contents of Table III shows that this is unlikely because a large proportion of the engines listed are small and will probably run at speeds above 1,000 r.p.m. Undoubtedly, although there are a few exceptions, curve B gives an optimistic view of the average specific weights of engines of recent British manufacture. One of the exceptions, a well-known

engine-maker, has provided details of powers and weights (exclusive of starting batteries) for three engine sizes, the first two of which show specific weights 5 per cent lower than those shown on curve A for equivalent powers, but the specific weight of the third and largest engine is 30 per cent greater and lies on curve B. This indicates that British manufacturers are already alive to the weight question and that the specific weight of engines will eventually become equal to, or even less than, those of the equivalent alternators.

Basic Law Relating Torque and Specific Weight of I.C. Engines. It seems logical to assert that a well-defined law exists relating the torque and specific weight of I.C. engines. It is now the fashion to retain the m.e.p., the cylinder bore: stroke ratio and the maximum piston speed at approximately constant values for any engine size, at least within the range of powers discussed in this paper, and these values are effective in fixing the basic engine size. Engine weights are affected to some extent by the maximum value of their rotational speed, but this can be settled at a definite maximum value, thus allowing the weight of the moving parts to be assessed for a given range of engines. Referring again to Fig. 1, it will be observed that particulars of air- and water-cooled engines by the same manufacturer closely surround curve A within a power range of 10:1 for the air-cooled engines alone and that this range joins up with that for water-cooled engines up to 200 h.p., a total range of 25:1.

The other points which closely adhere to curve A belong to a line of engines manufactured by one of the best known manufacturers in the United States. These engines, of rugged design, are manufactured chiefly from iron castings and show that good and cheap engines can be designed to follow a basic law relating torque and specific weight. By a remarkable coincidence this law is the same as that applying to alternators of corresponding output. Using this curve as a standard of reference, cast iron engine weights (which need not be exceeded) can be predicted for any power. The market price, which must be settled on what the customer buys, that is, on engine torque, enables the ideal price per unit of engine weight to be determined.

Basic Market Price of I.C. Engines. Several engine manufacturers have kindly made available the selling prices of their engines and when the ideal weights obtained from curve A (Fig. 1) have been used as divisors the figures obtained remain very nearly constant throughout a wide range of torque at 8-10s. per lb. for engines of similar construction having the similar accessories. In view of the fact that market values from engine to engine must be arbitrarily selected the result indicates that a reasonable uniformity in price already exists. There is no reason why this relationship should not be present, provided the price fixing has been accurate and based on engine costs, because these costs are governed by the design constants already mentioned. Appendix I gives further details of the deduction of the above figures.

Engine Torque Variation. The amplitude and frequency of the cyclic variations for a given engine depend among other things on the number of power strokes per revolution and on the number (N) and distribution of the cylinders. Assuming 4-stroke engines and a firing order such that each power stroke is equally displaced. then the fundamental frequency of the cyclic variation is (N/2) (r.p.m./60) per sec., that is 12½ c/s for single cylinders and 75 c/s for 6-cylinder engines running at 1,500 r.p.m. Analysis of the torque variations of many

engines shows that harmonics of considerable amplitude are often present. Normal load variations such as those that occur when driving welding generators will not usually be cyclic in nature and are unlikely to cause trouble due to tuning with any natural frequency.

Disturbances due to Possible Resonance Effects. Cyclic variations of engine torque must receive careful attention because they may give rise to two types of disturbance. If the natural frequencies of the revolving parts is not considerably different from the forced frequency developed by the engine, torsional vibrations will occur which may result in the failure of some of these parts. It is usually found that the natural frequency of the combined rotating parts, the engine crankshaft, flywheel and generator rotor, is sufficiently greater than the engine fundamental forced frequency, but in some instances investigation has shown that this is not so and resort to couplings damped torsionally is necessary. With standardized power packs, on which a wide choice can be made of the magnitude of any of the many variables which contribute to fixing the natural frequency of the revolving masses, there should be no difficulty in avoiding the reasonance conditions.

With generators in parallel supplying a common bus bar, the electrical system is flexible and has natural frequencies of oscillation. If the the torque impulses of any of the engines coincide with any of these the system will oscillate, current surges taking place between the generators, resulting in overheating of the armature and voltage disturbances. A cure can be effected if the resonance condition is removed by a modification of the stored energy content of the revolving masses.

Engine Damping. The disturbances mentioned under the previous heading can be kept smaller if engine damping is made more effective. A proportion of the engine damping is due to elastic hysteresis of the revolving parts; a much larger proportion is due to the motion of the crankshaft in its bearings. Usually the double thickness of the retained oil film in these bearings is of the order of 0.003 to 0.005 in. and it is conceivable that the total movement of the crankshaft within the journals may be of the small order of 0.0015 in., but the energy absorbed in making even this small motion many times per second is large. Further improvements may be possible in this direction by increasing the movement of the revolving parts; for instance, doubling the number of bearing sleeves radially would allow double the movement and would absorb twice the energy. The use of energy-absorbing mountings for the bearings might also be possible, the limit to this being the effect of the movement on the engine itself or on the unit it is driving.

On the Possible Use of Air-Cooled Engines in Standardized Power Packs. It would appear that 4-stroke engines of two speeds with normal electric starting apparatus would cover the whole range required for standard power packs, as the maximum power required would not exceed 200 h.p. and there already exists a sufficient range of water-cooled British engines to cover all the proposed pack requirements. In view, however, of the many difficulties of water cooling, such as the necessity for clean water supplies, danger of freezing or overheating, leaks, scale deposit, delicate cooling apparatus and also the fact that there exist air-cooled engines which have specific weights less than those of the corresponding average British water-cooled engines, it may be desirable for British engine designers to look to air-cooling for future requirements. It is

claimed for the air-cooled engine that the faster warming up facilitates starting, reduces fuel and lubricating oil consumption and cylinder wear. Experience has shown that the life of air-cooled cylinder liners is two to three times that of water-cooled equivalent and that the lubricating oil lasts twice as long.[7]

GENERATORS

Basic Rating. Industrial generators are normally rated in accordance with B.S. 168 (1936) and generators for service requirements in accordance with B.S. 1156 (1945). The two specifications limit the permissible temperature rise for various parts of the machines, the permitted temperature rise in B.S. 1156 being 5°F. higher than in B.S. 168. This difference is in the overload allowance of 10 per cent in current permitted by B.S. 1156, whereas B.S. 168 permits a 25 per cent current overload.

Factors affecting the permitted temperature rise are the altitude at which the generator will operate, and the ambient temperature there. The standard temperature rises given in both specifications are based on an altitude not exceeding 3,300 ft. above sea level, and a temperature of cooling air not exceeding 40°C.

Loss of Output due to Departure from Basic Conditions. When the standard conditions do not apply, a reduction must be made in the permitted temperature rise, that is, the generator must be derated. For the same extreme conditions as used in Table II, the percentage derating of the generator, based on B.S. 1156, would be as shown in Table IV.

TABLE IV

		Derating per cent		Derating per cent
Altitude, ft.	500	0	5,000	7½
Temperature, °F.	125	26	90	0
Totals		26		7½

For the generator, no correction is required on account of humidity.

Specific Weights and Prices of Alternators. Curve A in Fig. 1 is constructed from the details given in Table V and the average specific price of £670 per ton (6s. per lb.) is within ±4 per cent throughout a power range of 10:1. Since the values are fixed arbitrarily this coincidence is remarkable.

Brief Comparison of the Operation of the Magnicon Generator with D.C. *Generators.* Probably the simplest method of explaining the working of the new generator is to compare its characteristics with the well-known D.C. dynamo, because these are very similar, particularly in the ability to unload when short-circuited and the stability at various voltage levels. It is well known that as the current is increased in a shunt generator field the terminal voltage rises rapidly until magnetic saturation occurs. As the increase of voltage becomes less with increasing field current a balance is soon attained when the terminal voltage is

just sufficient to supply the field. The regulation is poor unless a compound winding is used to retain the voltage level from no load to full load.

The Magnicon exciter control circuit consists of two windings, 2 and 3 (Fig. 2), the magnetic effects of which are opposed to each other, coupled in series and carrying only the very small control current which is supplied from the generator terminals through a rectifier. One of these windings (2) with the greater number of turns operates on a highly saturated magnetic circuit, the other (3) on a magnetic circuit in which, throughout the working range, the saturation is negligible. These coils produce opposed fluxes which in turn produce voltage in the armature conductors under the pole parts on which they are wound. As the control current is increased the voltage difference produced in the armature first increases then decreases to zero and a further current increase reverses the armature voltages.

In the Magnicon exciter a double-duty winding carrying the secondary or output current and balancing the armature reaction of the output stage is fitted to protect the control poles and the winding is also provided with a little extra strength of such an amount that it maintains the terminal voltage of the main generator at a constant value. The action is similar to that of the compound winding: the shunt-wound dynamo, however, can unload but cannot retain level voltage; the compound-wound dynamo can retain level terminal voltage but cannot unload. The Magnicon generator retains both these properties with

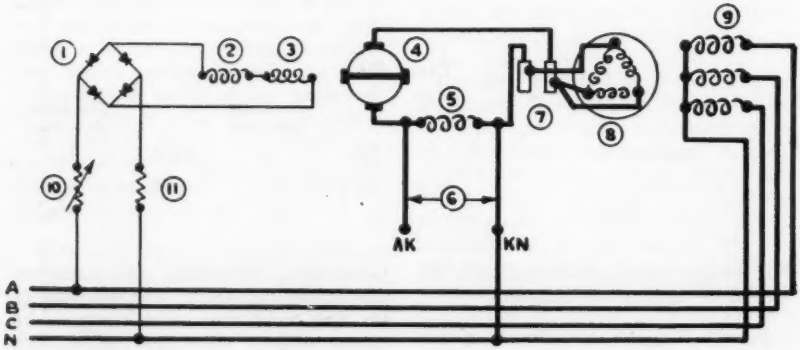

Fig. 2.—Circuit diagram of Magnicon alternator.

(1) Rectifier.
(2) Saturated field.
(3) Unsaturated field.
(4) Amplifying dynamo.
(5) Compensating winding.
(6) Paralleling leads.
(7) Alternator field slip-rings.
(8) Alternator field.
(9) Alternator armature winding.
(10) Hand voltage regulator.
(11) Ballast resistance.

the further advantage of exceptionally rigid control over a very wide stability range.

Advantages of the Magnicon Generator. The advantages of the Magnicon generator may be summarized as follows, the first four items being primarily of interest to the engine-maker and the remainder to the user:

1. They are smaller in diameter and less in weight and cost for a given output and speed.

2. Because of their stabilizing qualities at various levels, $\pm 2\frac{1}{2}$ per cent on a voltage range from the same generator at constant kVA. output is a standard commitment.

3. Revolving field designs together with the ranges mentioned above enable all standard voltages to be obtained from a single generator of given output by suitably coupling stationary windings. Further, the same performance is obtained at any frequency between 50 and 60 cycles with increasing generator voltage and power in proportion to the speed if desired and if the control circuit resistance is suitably altered. The standard generator will develop the same voltage and power at any frequency within the specified range without any alteration whatever, maintaining the same voltage regulation at any level.

4. No separate regulating apparatus (A.V.R.) or special synchronizing or paralleling devices are required, therefore the size and the cost of the switchboard is considerably reduced.

5. Automatic close self-regulation practically independent of the normal variations of temperature, speed, load and power factor, without the use of separate apparatus.

6. Due to the use of the paralleling links, the special field winding, and the unloading V.A. characteristic, paralleling may be accomplished without the use of auxiliary apparatus. Magnicon generators also share the load more closely and easily than conventional types.

7. Revolving fields are produced without extra cost and the advantages gained are listed earlier in the paper. Apart from allowing the power winding to remain stationary, these are chiefly concerned with simplification and maintenance.

8. As the short-circuit current falls nearly to zero, the generator cannot be damaged by prolonged running under this condition.

9. The effect of out-of-balance currents on the regulation in any phase is less than one-third that of the conventional dynamo. The balancing effect of the field winding is such that 3-phase generators with one phase omitted are suitable for single-phase working at approximately 75 per cent of the output.

10. The terminal voltage of the generators under Magnicon control can never rise appreciably above the operating e.m.f. for which they are designed, even if the control circuit is accidentlly ruptured or the engine reaches its overspeed limit.

11. The simplicity of the system and the lack of delicate ancillary apparatus for regulating and paralleling not only reduces maintenance but enables semi-skilled, easily-trained operators to be used with less risk of accidental damage than in operating with conventional apparatus.

Possibilities of Magnicon Control on D.C. *Generators.* Where A.C. generators are to be used, constant speed is necessary to maintain constant frequency. With D.C. generators and small power control circuits, it is possible to obtain voltage regulation which is quite independent of variations in the speed, temperature, load and the like. Such

generators are in use for Post Office work and stand-by sets. They can be designed to hold terminal voltage constant over a wide speed range, with consequent saving in fuel and upkeep and in this instance the prime mover need not be governed. For example, with an ungoverned engine a small solenoid may be used to operate the throttle to idle the engine on light load with a consequent considerable oil saving, the terminal voltage remaining constant. When load is applied the solenoid operates to accelerate the engine to normal. Many generators of this design are in operation driven by ungoverned water turbines.

SWITCHGEAR

For A.C. *Generators.* Simplification of the switchgear by the omission of the A.V.R. and the special paralleling devices required by conventional A.C. generators makes it easier to provide space on the switchboard for engine apparatus such as gauges for oil and water temperature or pressure, battery charging ammeter, engine shutdown indicators, throttle control and starter push-button.

The electrical switchgear in its simplest form consists of one voltmeter with selector switch and fuses, 3 ammeters, a very small hand regulator for the voltage adjustment and one triple-pole switch-fuse unit with an additional 5-amp, capacity blade for making the paralleling connection AK (shown in Fig. 2). The simple switchgear is suitable for Magnicon generator control even when run in parallel with their neutrals solidly coupled for, due to the absence of triple harmonics in their voltage wave shape and possibly also to their rigid control while in parallel, triple-frequency currents flowing in the connected neutral are relatively small at all loads.

A.V.R. controlled conventional generators paralleled with the aid of additional current transformers may give trouble in this respect, particularly if they are of different manufacture and size, because their wave shapes may

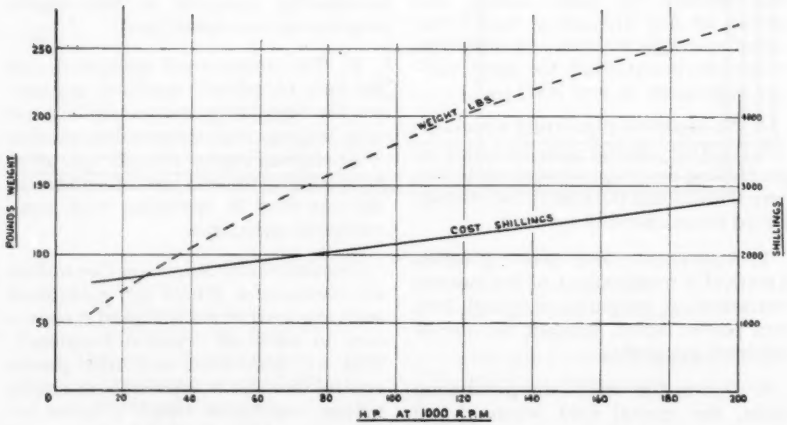

Fig. 3.—Weights and prices of switchgear for alternators.

not only differ at no load but will also differ due to the absence of armature compensation under load changes and to different degrees of magnetic saturation caused by varying operating conditions. To avoid triple-frequency currents the practice of carrying a neutral wire to one generator only is sometimes adopted. This method serves only if the loads on each line are always nearly in balance, but it is dangerous if the loads are even moderately unequal because the generator to which the neutral wire is connected must act as a center wire dynamic balancer for all the others and may motor so that its engine is actually driven against its own compression. This condition is determined by the out-of-balance load taken from all the paralleled generators. A method sometimes used to avoid this difficulty is to connect the neutral wire to a separate static balancer, relieving the generators from the balancing duty, and this enables all the engines to develop their full power if desired. So far as the authors' experience has gone, it has been unnecessary to adopt the balancer with Magnicon alternators in parallel.

The simplicity of the switchgear required by the new alternator allows approximate weights and prices to be plotted (Fig. 3) as functions of the h.p. output at 1,000 r.p.m. of the generator.

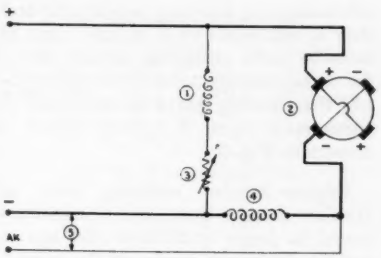

Fig. 4.—Circuit diagram of compensated D.C. generator.
(1) Shunt field.
(2) Armature.
(3) Hand volts regulator.
(4) Compensating winding.
(5) Paralleling leads.

For D.C. *Generators.* The switchgear required for D.C. generators will, in its simplest form, consist of one voltmeter and fuses, one ammeter, a hand regulator for voltage adjustment and one double-pole switch-fuse unit with an additional 5-amp. capacity blade to make the parallel connection A_1K_1 shown in Fig. 4. Two main and one 5-amp. paralleling terminals are also provided.

COUPLING BETWEEN ENGINE AND GENERATOR

Introductory. The standardized electrical generator leads to a further simplification in the design of the complete unit, namely, the closely coupled power pack in which the generator and engine frames are rigidly butted together to form a single rigid structural member.[1] The generator rotor has only one bearing. The advantages of this method are that the shortest possible pack is obtained; that aligning of the engine and generator shafts is automatically provided; and that the set can be supported on flexible mountings from both engine and generator at points placed in correct relationship to the centre of gravity.

The flexible mountings have several purposes; to prevent racking of the unit due to misaligned feet or warping of the bedplate on uneven ground; to allow interchangeability without close jigging of fixing holes; and to help to damp the engine vibrations. In small sets the rotating member of the generator is usually bolted directly to the crankshaft. In larger units some

allowance for warping is desirable and this is achieved by a simple type of flexible plate coupling, which allows for some misalignment while still holding the rotating parts co-axial and is torsionally rigid. A typical layout is shown in Fig. 5.

Engine-driven welding sets of similar design have been manufactured in large quantities and are in service in many parts of the world, some of them driven at 1,500 r.p.m. by Diesel and petrol engines of over 100 b.h.p. capacity. The couplings through which welding dynamos are driven are subjected to severe torsional shocks and to more onerous conditions than those used for transmitting power to normal A.C. or D.C. generators. This is due to the nature of the welding process, in which the transfer of the metal to the work takes place mainly in the form of molten drops, the frequency of the formation and the size of which are fairly constant for any given condition. Every time a drop passes, the generator is subjected to a considerable change of driving torque which may be large in comparison with the crank effort values. Recently experiments made with this type of coupling, having a centring pintle passing between the crank and rotor shafts, show distinct wear on one side of the pintle. This indicates that while the elastic plate is tending to keep the rotor central against the crankshaft displacement, the pintle is beating against the rotor, tending to make it follow this displacement. If a pintle is fitted—which is not recommended—an improvement on the damping of the whole system could be achieved either by a surrounding oil film or by mounting a damped sleeve upon it.

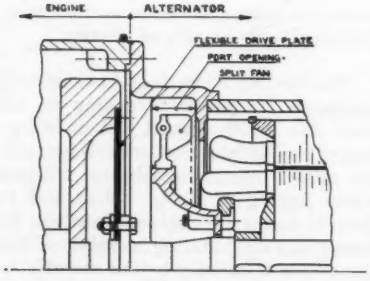

Fig. 5.

Bolting Generator to Engine. The following conditions should be observed in considering the assembly of generator and engine:

(*a*) That the flow of ventilation air is in the correct direction and is not in any way restricted.

(*b*) That the generator need not be dismantled in order to couple frames and revolving parts together.

(*c*) That the bell housing, corresponding generator flanges, and coupling details should be accurately machined to some standard dimensional specification.

The engine cooling air should be drawn into the pack at the end occupied by the electrical machinery so that the ambient temperature in which the generator operates is the lowest possible. The generator fan—if of the suction type—must be placed at the driven end and be of larger diameter than the generator rotor core. Unless the fan is split and can be removed in two parts, the usual method of assembling, that is, threading the stator over the rotor already *in situ* must be adopted. A simple method, shown in Fig. 6, of fitting or removing a two-part fan has been adopted by the authors, each part being inserted or removed through the side ventilation ports in the end shield. Two ports are provided to ensure that the fan capacity is fully used; these openings also allow easy access, before the fan is finally assembled, for bolting the coupling disc to the flywheel.

In the Handbook of the Society of Automotive Engineers (S.A.E.) of New York, details of dimensions of engine flywheel housings are given. Fig. 7 and its accompanying table give particulars of 5 generator frame sizes manufactured to fit engines having S.A.E. flywheel housings which appear to fit in well with the general overall dimensions of these generators.

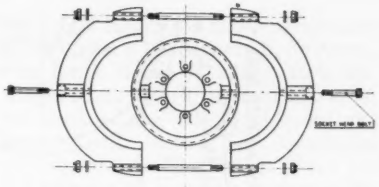

Fig. 6.

TABLE V

ALTERNATOR OUTPUTS AND CORRESPONDING NET ENGINE POWERS AT 1,000 R.P.M., ALSO NET WEIGHTS AND MARKET PRICES

Frame	Maximum alternator output No. kVA.	h.p.	Efficiency per cent	Net h.p.	Alternator weight lb.	Approx. market price £
2	15	16.1	84	19.2	910	304
2A	25	27	87	31	1,230	369
3	56	59	89	66.3	1,840	544
4	95	102	91	112	2,680	825
5	200	215	92.5	233	4,250	1,205

THE POWER PACK

Anti-Vibration Mounting. An important consideration is the method employed to provide efficient anti-vibration mounting between the set and a suitable base or foundation. If the action of this mounting is satisfactory and the engine damping good, it will be unnecessary to provide elastic mounting for any of the individual parts. The Magnicon generator, with its in-line exciter and its rectangular end shield giving access to the exciter commutator and generator slip-rings from both sides, also provides an entry for cooling air. All can be mounted on the generator, switchgear and the engine instruments in a box of about 2 cu. ft. in volume, rigidly bolted to the top face of this end shield. To achieve this simplification it is well worth while paying great attention to the anti-vibration mounting of the whole set. Conical buffers offer good facilities for damping and have been used with success for many years, absorbing the energy of vibration of overhung centrifugal machines, some of which have baskets 4 ft. in diam. and 3 ft. in length carrying total suspended weights approaching 1 ton. These baskets may be run up to 1,500 r.p.m. with considerable out-of-balance loads without showing undue vibration throughout the whole speed range. Buffers of the type indicated in Fig. 8 could be used as power-pack supports, probably using two in line, but this would involve the use of torque rods between the base and suitable attachment points on each side of the power pack. The use of 3 buffers, 2 under the engine and 1 under the generator, would avoid the necessity for torque rods. The angle of the buffer cone is important.

Specific Cost of Export Power Packs. Details taken from Table III were used to make an approximate check on the weights of engines of

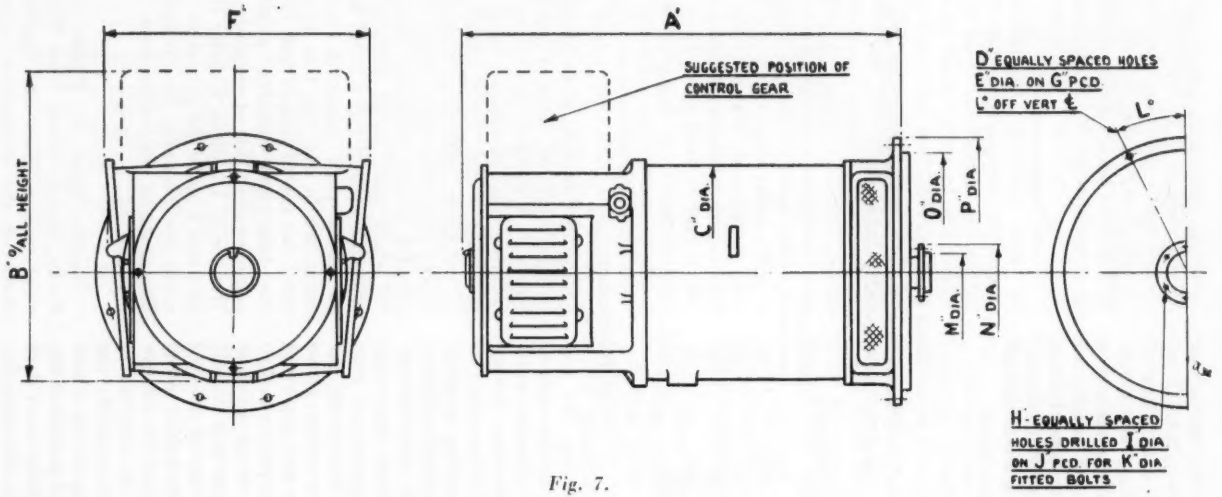

Fig. 7.

Carcase	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	To fit engine housing
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	°	in.	in.	in.	in.	
2	34	27 5/8	16	12	7/16	21	18 3/8	6	31/64	4 3/4	1/2	15	3	5 1/4	17 3/8	19 1/4	No. 2 S.A.E.
2A	41 5/8	28 5/8	18	12	7/16	23	20 7/8	6	31/64	4 5/8	1/2	15	3 1/4	6	20 1/8	21 7/8	No. 1 S.A.E.
3	47 21/32	33 3/4	20 1/2	16	9/16	24 3/4	26 3/4	6	33/64	5	5/8	11 1/4	3 1/2	6 3/8	25 1/2	28	No. 0 S.A.E.
4	49 11/16	35 1/2	24	16	9/16	30	26 3/4	6	33/64	5	5/8	11 1/4	3 1/2	6 3/8	25 1/2	28	No. 0 S.A.E.
5	53 15/16	38 1/2	30	16	9/16	37	30 1/4	6	47/64	6 1/2	3/4	11 1/4	4	7	29	31 1/2	No. 0 S.A.E.

British manufacture. From the same source particulars are available of the exports of Diesel-driven generators. For powers up to 200 kW. 9,100 tons weight of a total value of approximately £4,900,000 were exported in 1952, that is, at a specific cost of £540 per ton. Earlier in the paper the specific cost of British engines was assumed to be a maximum of £700 per ton on

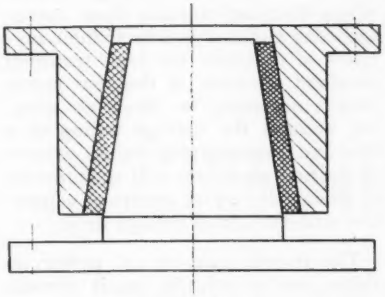

Fig. 8

the weight basis of curve B (Fig. 1) but for power packs the alternator figure is £670 per ton, hence the relevant total figure for these units must be less than £700 per ton. If, however, this latter figure is taken, then the weight ratio is 1:3, that is, about 30 per cent. of the weight of each unit covers such details as bedplates, switchgear, etc. The details given for the exports of complete power packs provide a better check on the weights of British combined manufactures than those already given for engines alone.

A Method of Estimating the Approximate Weights and Market Values of Power Packs. Fair values for what should be the weights and market prices of power packs can be obtained by the use of curve A (Fig. 1), and the specific price constants referred to in Appendix I. As an example, assume that the weight and price of a 70-kVA., 1,500-r.p.m. alternator unit of standard voltage and frequency is required. As the generator is required to produce $70\times(1{,}000/1{,}500)\times800/746$ h.p. output, that is, 50 h.p. at 1,000 r.p.m., and the engine $50/0.89=56$ h.p., the weights and prices must be estimated on these outputs as in Table VI.

TABLE VI

		Weights using curve A Fig. (1) for engine and altenator lb.	Price s.
A	Engine, at 10s, per lb.	1,800	18,000
B	Altenators, at 6s, per lb.	1,700	10,200
C	Switchgear, Fig. 3	120	1,800
D	Undercarriage weight taken as 1/7th of (A+B+C) at 1s. per lb.	515	515
	Total for the complete power pack without covering canopy	4,135	30,515
		1.84 tons	£1,525

CONCLUSION

It may be useful to repeat that, although the world's demand for more soucres of electric power is now very great, this demand is still increasing so rapidly that it is now an urgent necessity to standardize a high-class British power pack. The electrical unit has hitherto constituted the chief ob-

struction to efficient standardization, but by designing along the lines indicated, not only are A.C. and D.C. generators and their switchgear made physically interchangeable but the space occupied by these being less than that for conventional types, it is easier to adapt the parts to build up into closely coupled units of small dimensions.

The prime mover and its associated apparatus may therefore be completely standardized for all generators of equivalent rating. Adapting end-bells, bedplates, canopies, etc., for each job becomes a thing of the past and bedplate aligning is unnecessary. Moreover, the user obtains a lighter, more compact and more efficient pack, having easily replaceable standard parts, at a first cost which should be less than that required for the older and more haphazard production. The high-speed Diesel engine is now a very reliable and efficient machine and there is no reason why low-speed units (requiring about ¼ ton of concrete per bed per installed h.p.) should be used, even on permanent sites.

In many instances it will be more economical to install two machines of half the power in place of one low-speed unit (even in actual capital cost) and gain the advantage of spare plant, fuel economy in light-load running, less wear and tear and more ready maintenance. Further, the modern generator is so versatile that new applications for power packs will be found in ever-increasing numbers, as, for instance, in the present tendency to operate marine auxiliaries on A.C. circuits using plain squirrel-cage motors with direct-on starters on every practical occasion. One limitation that arises with conventional generators when designed to suit their corresponding engine capacity is their inability to maintain the high transient overload currents at the low power factors necessary for direct-on starting without the voltage falling to a low and unacceptable value, whereas the new generator will start motors of practically equal electrical capacities without undue voltage drop.

The introduction of A.C. power on ships, particularly in small vessels, will result in easier solutions of many of the difficulties that still remain with D.C., particularly in supply, distribution, transformation and switching. There are many other new uses to which suitable power packs can be adapted and all the necessary data is now available. If energetically adopted there is no reason why the British manufacturer should not become the world's major producer of these units.

BIBLIOGRAPHY

(1) "Reflections on Electrical Power Packs," by J. C. Macfarlane, J. W. Macfarlane and W. I. Macfarlane. *Engineer*, 1946, col. 182, p. 550.
(2) "Automatic Voltage Control of Generators," by C. Stewart. Journ. Inst. Elec. Eng., 1947, vol. 94, pt. IIA, p. 39.
(3) "Inherent Current Voltage and Speed Control in Dynamo-Electric Machinery," by J. C. Macfarlane, J. W. Macfarlane and W. I. Macfarlane. *ibid*, 1952, vol. 99, pt. II, p. 421.
(4) "The Magnicon," by J. Griffin. *Electrical Times*, 1951, vol. 119, pp. 596 and 646.
(5) "Direct-Current Arc-Welding Generators and Systems," by J. C. Macfarlane, J. W. Macfarlane and W. I. Macfarlane. Journ. Inst. Elc. Eng., vol. 93, pt. II, p. 603.
(6) British Internal Combustion Engine Manufacturers Association Catalogue. 1952.
(7) U.S. Diesel Engine Catalogue, 2nd Edition, 1952, vol. 17.
(8) "Internal Combustion Engines," Internal Combustion Engine Productivity Team, 1950. Anglo-American Council on Productivity. London and New York.

TABLE VII

Engine		H.p. at 1,000 r.p.m.	Engine weight lb.	Engine specific weight lb. per h.p.	Corresponding alternator specific weight lb. per h.p.	Percentage difference	Engine market price £	Engine weight on alternator basis tons	Specific market value on alternator basis £ per ton
A	1	29	1,500	51·8	44	18	523	0·569	920
	2	36	1,600	44·5	40	11¼	560	0·642	873
	3	43·5	2,000	46	36·5	26	684	0·71	965
	4	59	2,500	42·5	31·5	35	768	0·83	925
	5	91	3,250	35·7	27	32	984	1·10	863
	6	100	3,400	34	26·5	28	1,059	1·173	903
B	1*	27	1,708	63	45·3	40	390	0·546	715
	2*	36	2,100	58·5	40	46	495	0·643	770
	3	50	2,688	53·8	34	58	750	0·75	985
	4	66	3,853	58·5	30·5	95	890	0·9	990
	5	100	5,936	59·36	27	122	1,190	1·2	990
C		33	1,290	39·2	40	−2	515	0·59	873
D									
E*		7	330	47	70	−32	154	0·22	700
F	1	42	1,480	35·3	37	−4·5	810	0·693	1,170
	2	64	1,700	26·6	30	−11	960	0·860	1,120
	3	100	3,650	36·5	27	+35	1,875	1·2	1,560
G	1	57	2,100	37	32	15	880	0·815	1,080
	2	80	2,500	31·3	28·5	10	1,200	1·02	1,180
	3	107	3,000	28	26	7·5	1,500	1·25	1,200
H	1	36	1,430	40	40	Zero	711	0·643	1,110
	2	62·5	2,300	36·6	30·5	20	968	0·84	1,150

* Hand starting

APPENDIX I

Table VII gives details of the weights and approximate values of I.C. engines of several British manufacturers. It was the original intention to include in the engine weights and prices, every normal accessory, for example radiator, fan, exhaust system, fuel tank, electric starting equipment (without battery), but such items as radiator supports, flexible piping, drain taps for the filter system and even silencers may have been missed in this approximate survey. Nevertheless, although the basic information may not be uniform. Table VII reveals the tendency of British engines to reach uniform weight values, and specific market prices to become constant over wide output ranges. Fourteen engines, A to E, have a specific market price averaging between £900 and £1,000 each, whereas this figure lies between £1,100 and £1,200 for the 7 engines F to H.

Engines B1, B2 and E are arranged for hand starting, but if the extra price for electric starting for each of these is allowed for their specific values would also be well within the limits of £900 to £1,000 Although engine E is very light (being constructed chiefly of light alloys) it provides a contrast to engine B5 which is very heavy, but both fall into the same category when compared on the basis of alternator weight.

APPENDIX II

The reason why the specific cost of I.C. engines remains fairly constant over a wide range of outputs is that the value of any material is dependent only on the value of the man-hours expended to produce it; for example, a ton of coal when brought to the surface has a value strictly proportional to the work done in raising it. If it be assumed that the final value of an engine in man-hours at the usual rates is 100 per cent., this might be divided approximately as follows: 30 per cent. for what is usually called raw materials and 70 per cent. for labor, overheads, and a profit on the turnover. For electrical machinery those proportions are assessed reasonably accurately (and do not vary appreciably from year to year) at 50 per cent. for material, and 50 per cent. for the remainder of the items, if the material (as is usual) consists of finished core stampings, insulated and formed copper, unmachined castings, such accessories as brushes, ball-bearings, and the like. In considering the specific cost of a range of engines there is no reason to assume that the specific cost of the raw materials used in small engines is different from that for large engines, and it is reasonable that the man-hours' cost accumulated during completion in a manufacturer's works is in quite good proportion to the weights of the materials used, particularly when the engine power, man-hours consumed and weights may be raised by the use of an increased number of cylinders only. Finally, the use of a relationship between torque and specific weight as indicated by curve A, Fig. 1, discloses the anomalies between engine ratings which appear in Table VII. These could presumably be eliminated to give a range of engines having uniform maximum power: ratios.

ECONOMY

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THE AUTHOR

was born in Manchester, England, in 1893. Educated Manchester College of Technology. With Royal Engineers, British Army 1914-1919, Egypt, Gallipoli, Sinai, France, Belgium, Industrial Engineering experience includes special apprenticeship and supervisory positions with Churchill Machine Tool Company, England, in the building, design and engineering selling of precision grinding machinery; in 1926 as Director of Engineering, Cincinnati Grinders, Cincinnati Milling Machine Company; 1934 Chief, Machinery Division, U. S. Department of Commerce; 1935 Vice-President Chambersburg Engineering Company; in War II, on staff of Assistant Secretary U.S. Navy, and later as Special Assistant to the Under-Secretary, Registered Mechanical Engineer in Ohio, New York, Pennsylvania, Maryland and District of Columbia. Fellow ASME and Royal Society of Arts; Member other Engineering Societies in USA and Europe. Present Duty, Industrial Engineer, Field Activities, BuShips.

"I place economy among the first and most important virtues, and public debt as the greatest of dangers to be feared. To preserve our independence, we must not let our leaders load us with perpetual debt. We must make our choice between economy and liberty, or profusion and servitude. The same prudence which in private life would forbid our paying our money for unexplained projects, forbids it in disposition of public money. We are endeavoring to reduce the government to the practice of rigid economy to avoid burdening the people and arming the Magistrate with a patronage of money which might be used to corrupt the principles of Government."

—THOMAS JEFFERSON

The foregoing represents something pretty close to the quintessence of good horse-sense.

The guidance is specific. It is the antithesis of generalization.

Current pronunciamentos on the subject of economy are frequently masterpieces of generalization, and as such tend to defeat the accomplishment of the very purpose for which they are designed.

Dangers of generalization are always present, and current examples, wherefore Government Departments are castigated for alleged wastefulness and inefficiencies, particularly the Armed Services, are no exception.

The present call for more economy is completely justified; economy is

always a worthy cause. The galloping diminution of the purchasing power of the U.S. dollar is a strident warning for all of those with eyes to see, and ears to hear, that it is time to call a halt to our excessive national expenditures, or face the consequences of national bankruptcy.

The assumption, however, of some of the ruling politicos that heads of Government Departments lie awake of nights planning ways in which to dissipate the taxpayers' hard-earned dollars, has been expressed so often in terms of broad generality, that the need for corrective action has not always been generated, and in its place there tends to develop a feeling of indifference.

While exhorting the services to practice greater economy, it should be noted that economical operation has always been, and always will be, an essential characteristic of the Navy. The Navy depends for its life on the effective economical manipulation of machinery, which is of the very essence of this Service's ability to fulfill its mission—a situation which has existed in accelerating degree since the transition from sail to steam.

From the day of his indoctrination till the day he retires, the Naval officer must possess, as an essential part of his professional proficiency, an instinctive capacity for economical operation. The last knot of available speed attained with the minimum rate of oil consumption, the ultimate of total miles of cruising radius on oil bunker capacity, the maximum damage to the enemy with the smallest expenditure of missiles, and last but by no means least, the aviator, returning from a distant mission, seeking his carrier, must forever keep before him that his ability to get back to the deck is dependent on the training which enables him to stretch out his fuel supply. In all of the foregoing, it is the ability to survive which is at stake. Truly, the ultimate penalty for the uneconomical operator.

A ship at sea is an entity. There are no conveniently adjacent warehouses wherein to stow surplus gear. The very essence of good sea-keeping economy lies in the most efficient management of available space and supplies. Economy in the use of space and supply operation is a must. It is the sign manual of the efficient officer, and it all adds up to a type of training, which, ashore or afloat, makes the Naval officer abhor waste in any form.

It is hardly conceivable that personnel, so thoroughly trained professionally, could, under any circumstances, be consciously guilty of wasteful practices, especially when coupled with this training, is that additional education generated by having to live at an established standard on relatively meager pay and allowances.

WHERE CAN THE DESIRED ECONOMIES BE MADE?

The search, to be effective, must be all embracing, and as the larger economies necessarily must be generated at the top, a review of global missions could be in order. If the funds wherewith to support these missions are simply not available, then global missions, logically, must be contracted, or some of them abandoned.

Top management, having made sure that major missions are reduced to lowest safe minimum, next in line come searching reviews of mannings, ships, and facilities.

At this point, it is imperative that basic ground rules be recognized, promulgated and accepted; otherwise there exists danger that the professional Naval operator may be overruled and hamstrung by zealous civilian administrators, with disastrous consequences, spelled out in terms of

failure to accomplish the minimum required military missions.

It is as good a rule in Government, as it is in business, for individuals to stick to chosen professions. While the management of money cuts across all functions, there exists, however, a well defined deadline to professional knowledge and competence, beyond which neither participant in the discussion can step without endangering the end result, which both desire with presumably equal fervor.

THE MECHANISM OF ECONOMY BUDGETING

Careful budgeting is the proven tool which, if properly generated and administered, will accomplish the desired end, resulting in orderly, if not painless, solution of the problem of basic managerial planning.

Ground rules are simple, but rigid.

There is neither sense nor reason, and much less safety, in a condition of affairs where an operator, knowing that his budget submittal will be cut, deliberately asks for more than he expects to receive, hoping that the net allotment will amount to his preconceived minimum of funds required to cover essential operations. Unfortunately, human nature being what it is, this process has grown to be a practice, and it is only in its complete eradication that there exists hope of a permanently honest form of budget formulation.

Ground Rules

a. Budgeting must be done by thoroughly experienced, intellectually honest, professionally able personnel, drawing freely on best available professional Naval and fiscal advice.

b. The budget must be firm; it must be irrevocably tied to the missions assigned, otherwise personnel charged with accomplishment will lack confidence to the point where subterfuges will be automatically written in.

c. The budgeted funds must be promptly available for implementation on or before the period of applicability. The budget must intelligently anticipate requirements up to the limit of best human foresight.

d. The budget must be patterned on past experience, but with due regard to carefully anticipated needs of the future, not the next twelve months, or fiscal year, alone, but to the future of a country which expects to stay in business indefinitely. In other words, the budget must be a calculated contribution to the "mosaic" pattern of the nation's accepted destiny.

e. The budget, once devised and agreed to, must become the loyally accepted "bible" for every last hand in the Service. If it is as good as it should be, the measure of its careful execution is the yardstick of managerial efficiency and effectiveness.

Detailed Administration of a Policy of Economy

a. A constantly repeated indoctrination for all hands. The example must be faithfully set by the top echelon of management, and the indoctrination made a continuing effort down the line. The mere reiteration of the word economy, will accomplish nothing. It must be made as simple and direct as the lesson which is imparted to the small boy concerning playing with matches.

b. Staff discussions are a necessity, inasmuch as down the line supervisors, seldom knowing all the facts available to top management, are frequently at a loss to understand why some apparently expensive move is made, and get the impression that the boss's

talks on economy are largely lip service.

c. While the larger economies of operation must necessarily stem from the top, no detail of operational management should be too small to receive prompt, but not labored, attention. American operators are quick to learn and can soon appreciate that wastefulness can and does cut into their earnings.

d. In those organizations where economy of operation is now paramount, it is noteworthy that the "game" is played in the team spirit. The first essential of a good team, is a good captain.

Designer's Contribution

Economical operation, to be consistent, must stem from the grass roots of organizational thinking. For instance, economy in the use of materials starts in the mind of the designer long before he puts a line on paper, whether that line be on a drawing board or a line of type in a specification.

It is relatively easy to design machinery which will function satisfactorily when one uses the most expensive materials which are given the most expensive kind of processing treatment, but the smart designer is the man who can get functional reliability for anticipated life, while using more readily available and possibly cheaper materials, processed in a cheaper way. Competition between individual concerns, and competition between industries, provides the spur which generates this kind of thinking. All competitive business is, in principle, cannibalistic, and the wasteful operator soon becomes food for his better managed competitor, either through the medium of a merger at a bargain price, or as a result of bankruptcy.

Contracting Department's Contribution

The contracting, or purchasing department, which must, per se, procure raw materials and some of the finished components which go into the composite end product, next is in line to make its contribution to the economical generation of the end product.

It is in this department that the need for exercising of Solomon-type judgment exists in adjudication of the merits of bidders competing for raw material orders.

Just as the slow, over-cautious Mr. Milquetoast at the wheel of his automobile is as great a hazard on the highway as the speed hog, so the overly low bidder is invariably a major hazard to the program, and timetable, for the production of the end product. Experienced buyers soon learn to detect the green supplier who does not know his costs and, therefore, bids too low with all the miserable consequences which go with such an experience. There are few manufacturers who have not learned to echew the fly-by-night adventurer who will step in, and jimmy up the production schedule by failure to deliver, when he finds that delivery means a financial loss to himself and his company.

The process of selection of a reliable contractor can be reduced to an exact science, based on a simple quantitative qualitative analysis of that bidder's reliability in his own chosen field of endeavor.

Outlined on the next page is a typical example of just such an analysis of almost classical simplicity. The guidelines are simple. Avoid wherever possible, matters of opinion, and place reliance only on matters of provable fact.

It is a *sine quo non* of good organization that the purchasing, or contract-

BID ANALYSIS

Contractor Factor	Price	Delvy Relia-bility	Expe-rience	D&B	Reputa-tion in Local Labor Market	Facil-ities	Labor Avail-ability	Manage-ment	No. Yrs. in the Business	Score
Weighing	20%	15%	15%	10%	5%	15%	10%	5%	5%	100%
A	20	5	0	5	0	5	10	3	1	49
B	0	15	8	5	5	15	10	5	5	68
C	8	8	10	5	0	10	5	2	2	50
D	4	8	5	10	3	5	5	5	3	48

Award should go to Bidder "B."

ing, department, whether private or governmental, be intellectually honest enough to evaluate the simple word "reliable," which appears in the law which demands three bidders and the award of the contract to the lowest "reliable" bidder.

Weight percentages can be assigned to each of the factors making up the basis for the award of a contract.

The percentage of weight allocated to each element will, in all cases, vary according to the nature of the situation which exists. During wars it is not uncommon to allocate 50% or more of the merit points to the contractor offering the shortest delivery. In the example quoted above, which is assumed to be a peacetime operation, only 15% advantage is given to the contractor offering the shortest delivery (reliable).

The directors of purchases, of large industrial concerns, like the contracting officers of large and small government departments, must under all circumstances protect the interests of their employers by clearly defining "reliability" in the evaluation of a prospective contractor. Any official, either unwilling or incapable of doing this, is unworthy of his job.

Adherence to the foregoing broadgage rules insures the most economical overall procurement of the raw material from which the end product is made.

Production Management

The tempo of the times in which we live dictates the need for relatively high rates of remuneration for the manual worker who operates the machine tools of industry. Conservation of this expensive manpower is, therefore, a primary must for good operational management.

A few extra hours spent on the planning of the types and sequences of fabricating operation can be made to pay dividends in the form of savings of many hundreds of thousands of manhours after the raw material and the job tickets reach the machine shop floor. In such planning work there is no substitute for practical experience, and the savvy general manager will go to great lengths to insure that this reliable practical experience backed, of course, by equally adequate basic engineering training is really in control of his planning and processing department.

Economy in the field of manpower achieved through proper sequences of

operations, the elimination of unnecessary operations, and above all, the wise supervisory guidance of an inspection department which reports independently to general management and not to production management, all add up to economy of the first degree.

Welding in the Shops and in the Field is a phase of fabrication where much money and time can be saved.

An outstanding anomaly exists in the design phase of shipbuilding. The hull is designed to make the fullest use of its material components according to established criteria, but hull fittings, for instance, are still specified for which "Standards" were established more than twenty years ago. In addition, functional components are specified for which tailor-made foundations are required. Provision of standards incorporating simple, adjustable, attaching devices is an economic challenge.

Fabricating processes accrue which require the use of expensive castings which must be machined. Imperfections, particularly in small castings add to cost by either repair or rejection. Expensive incorporation techniques, such as silver soldering brass deck drains to a surrounding steel band to provide a weldable connection to the steel deck is a typical case of uneconomical specification. Hundreds of such fittings are required for each ship.

Mooring bitts is another instance of unrealistic standards. The junctures of the steel cylinder with base and cap are built up with a convex fillet weld and ground smooth to finish. As these fillet radii are not equal to the radius of the mooring lines, it is obvious that the cheaper method of fabrication would be to swedge the cylinders, or hot form in halves subsequently butt welded together, thus reducing the manual welding and grinding while retaining functional utility.

The problem of correct technique in the application of welding is apparent in almost all applications of fillet welding. Too little effort has been made to understand the technique of fillet welding and, as far as can be discovered, there is no publication which attempts to present, in workable form, the fundamentals necessary to a working knowledge of the theory of efficient design.

The General Specifications for Building Vessels of the U.S. Navy delineate a broad guide for design use of welded joints. It is obvious from a study of the table of efficiency of double fillet welds contained therein that this guide is not motivated by economy in fabricating costs.

In the smaller fillet, sizes 3/16 to 3/8 inch, within which a large portion of the workload lies, it is the rule to specify larger sizes than needed in this way:

Evaluation of actual requirements are not made in the design area in particular when the efficiency of the smaller weld exceeds 90%. Examination reveals an increase of welding out of proportion to theoretical gain. In these areas it should be realized that increases as small as 1/16 inch in leg length of a fillet weld result in overwelding that cannot be justified. This can readily be demonstrated by comparing the areas—hence material deposited—in this range.

Size of Fillet	3/16	1/4	5/16	3/8
Proportion	1	1.78	2.78	4.00
		1.	1.56	2.25
			1	1.44

In material requiring larger fillets, it is the general practice to ignore the probable economy of using groove welds. If this analysis were to be made part of a design requirements, it would be obvious to the designer that the thinner member is the weak link and the weld would be proportioned to develop the strength of that member.

A recent observation showed a 11/16 fillet specified where the strength of the thinner member would be developed by use of a 3/16 fillet. This represents an oversizing of more than thirteen to one requiring electrode purchase far in excess of actual need.

In practice, it is readily observed that the incentive systems in industry tend to reduce the ultimate effect of overwelding by the operator driving for footage with acceptable quality, while in government plants the accent is on quality and not quantity, resulting in overwelding.

Even as the budgeteer asks for enough to be able to accept the cut he knows will be made, those detailing welding appear to have been motivated by a desire not to be caught short.

The result is a definite need for education in the economics of welding specification and an insistence that processes best suited to economically producing the required result be utilized rather than taking the line of least resistance and specifying outmoded, expensive and uneconomical "Standards."

ECONOMY IS A HABIT OF THOUGHT

With a hypothetical product, whether it be a unit of machinery, a ship, a locomotive, or a house, ready to be turned over to the man who has bought it, a good searching look-back through the moves which were made to create this thing, can well be in order.

Sight must never be lost of the fact that dollar savings are made up in increments of cents, and a systematic paring of fractions of cent cost all along the line from designer's concept, to customer's acceptance, is the kind of treatment which creates the ground in which flourishes that delicate but beautiful little flower, known as an industrial profit.

CONCLUSIONS

There exists no basic difference between the task of confronting the executive of a commercial organization and the tasks of officers and civilian officials of the Armed Services. Many years experience in both capacities confirm this statement.

Most of the red tape, which businessmen find so irksome when assuming a government position, is necessary because of one very simple reason, i.e., in the spending of public funds the records must always be publicly available, and with relatively rapidly changing personnel, reliance cannot be placed on some individual's memory, hence, the red tape which is in essence the recording of significant actions within the chain of command.

Efficient business concerns keep minimum, but adequate and reliable, records of all transactions. Frequently records are a legal as well as a practical necessity, and furthermore as young sprouts qualify for minor management positions documentary records provide the intellectual fodder wherewith to feed their immature brains. The problem of properly bringing up the young men is forever before us, and those who neglect it, automatically encompass their own ruin. Good records greatly ease this task for all concerned.

The Jeffersonian philosophy, outlined in the preamble to this article, is of the very essence of the American concept of personal freedom reinforced with economy.

The philosophy of economy, interpreted in terms of everyday life, calls for the setting up of dynamic policy,

and this means actions rather than words. Under dynamic leadership, it rapidly becomes patent that good operational management demands that every participant subscribe to the creed of economical operation.

Words are great deceivers, and the worst offenders of all are the weasel words written into the voluminous memoranda which bedevil the military operator, now as always.

It is noteworthy that the great Duke of Wellington registered his protest in no uncertain words when he addressed the Secretary of State for War, in the following brief letter:

"My Lord—

If I attempted to answer the mass of futile correspondence that surrounds me, I should be debarred from all serious business of campaigning.

I must remind your Lordship for the last time, that as long as I retain an independent position I shall see that no officer under my command is debarred by attending to the futile driveling of mere quill-driving in your Lordship's office from attending to his first duty — which is, and always has been, so to train the private men under his command that they may, without question, beat any force opposed to them in the field."

Truly a case of adherence to a concept of economy in the professionally directed employment of men.

In the last analysis, it is the Navy's ultimate mission to fight, and it takes no great stretch of imagination, and draws not on the tortured mind of a savant to realize that economy in the use of available funds gives us more to fight with, hence improves our ability to do the kind of job that this great country deserves and demands.

SOME MANAGEMENT CONCEPTS FOR ENGINEERS

CAPTAIN R. E. W. HARRISON, USNR

The valuable contributions to engineering knowledge and practice made by the Battelle Memorial Institute are sufficiently well known to attest to their value. The following extract from the Battelle Technical Review, written by Clyde Williams, President of the Institute, indicates the growing percentage of engineers in the ranks of top management.

"Revolution in Industrial Management. One of the aspects of the Technological Revolution is the changed composition of industrial management. Recent surveys indicate that engineers occupy about 20 percent of the top executive posts in leading industrial corporations. Engineers now outnumber both lawyers and bankers as board chairmen and presidents of industrial corporations. In the newer industries, based directly upon the results of research, engineers and technologists frequently compose a substantial majority of the board of directors.

This shift in the makeup of management is, of course, an effect of the changed nature of our industrial economy. A highly technical industry requires men with technical training to understand and guide it. Competitive survival demands sound appreciation of technology at the policy-making level.

When any profession gains dominant voice in industrial management, our economic development reflects that dominance. Thus, when the bankers and financiers were dominant, we experienced great capital expansion and the development of our financial structure. The lawyers developed our corporate organization and lines of liaison with government. Sales people have put the accent upon mass marketing and consumption and have been responsible for our advertising and distribution systems. Technical people in management will inevitably think along technical lines and give impetus to technical development. Thus the Technological Revolution — which has put technologists into top management—will be stoked into great activity by the management it has created.

This can only mean more and more corporate research, greater competition, and better products for the public. It means, too, a different approach to economic and social problems. Technical people tend to think in concrete terms rather than in symbols and are likely to look askance upon proposals too far removed from basic concepts and principles. Thus, overproduction of a commodity will usually be regarded by the technologist as a sign of underdevelopment of its utility, rather than as a need for restriction of production. World problems are more likely to be thought of in terms of materials, energy, and resources, rather than in the usual terms of finance, control or political ideologies.

Engineers and technologists in management will also help further management relations with the public. The public appreciates the results of technical research and development and has high regard for the engineer's desire to maximize production. The laborer and tradesman can un-

derstand technical people, while they may have difficulty in understanding professions less closely allied with laboratories and shops. In turn the engineer and technologist understand the aspirations of workers all along the line and bring to the management team an insight into human nature as well as their guidance on technical decisions."

CLYDE WILLIAMS
President
Battelle Memorial Institute

This article, dealing with management concepts, is designed to draw attention to some of the aspects of general management which engineers need to brush up on as part of their training for assumption of ultimate responsibility.

The degree of acceptance or rejection of managerial responsibility governs the productivity of enterprise, whether it be the building of a new wing for The Church, the solving of the parking problem in D.C., the decision to use diesel electric instead of steam for motive power for a railroad, the purchase of some improved type machine tools for a factory, or, perhaps closer to home, the decision to buy, build or rent a larger house to accommodate a growing family.

Management's occasional evasion of its responsibilities for the provision of leadership can and does cost lives, money, time, security and good humor, and it is safe to say that due to the rapidly growing complexities of modern life, the mantle of responsibility which must be assumed by management now calls for a quality of perceptive brain power on a par with that which in former days would have been regarded as pure genius.

Fortunately for all of us, there has been a concomitant growth in the utility and productivity of the tools available to management designed as aids in analysis of problems, and execution of approved solutions.

This paper deals primarily with the question of responsibility for the provision of leadership. If the new wing to the church is not built economically and on time, who in the last analysis must accept the responsibility for what amounts to a dereliction of duty? If lives are lost at street intersections in the Capital of the Nation because of failure to deal with traffic and parking problems, who is the ultimate individual who can be called on to give an accounting for failure to do his obvious duty? If the XYZ Railroad approaches near bankruptcy because of its failure to compete for the passenger and freight traffic of the area it serves, who must take the rap for devaluing the stockholders' shares? If the ABC Factory must lay off its hands and splash red across its year-end balance sheet because its machine tool equipment will not compete in productivity with that of a fellow company in the same line of business, who must assume the stigma of managerial incompetence, and again, last but not least, if an otherwise sane and normal family breaks up, quarrels, and scatters to the four winds in disgust, who is the family manager who eventually must look Saint Peter in the eye and say, "I did this thing!"

As always, in common justice, the prisoner at the bar (after we have caught him) must, of necessity, be assumed innocent until proven guilty, hence, although in the long run the defaulting titular head of an organization may, and probably will, have to take the blame for the resulting confusion and loss, there may exist ameliorating circumstances which will dictate that he not be put to death, but that he at least subject himself to a course of instruction which will, in short order, induce him to mend his ways.

In those cases where top management defines and accepts the ultimate responsibility, the rectifying of mistakes is a comparatively easy matter

It is not nearly so easy to deal with the manager who has had written for him, or who has been permitted to write for himself, a constitutional set-up which permits him to dilute his responsibilities.

Much legal acumen has been expended in what might be termed the fine and almost unreadable print of such set-ups, but in the last analysis these organizational fog-bound areas border on evasion of responsibility, legal, moral and practical.

The management of a modern enterprise calls for the exercising of scientifically guided judgment predicated on ability to make broadgage analyses of each and every situation singly and in combinations as they may arise.

There exists no known substitute for adequate training in this science. Sound and completely effective decisions today are practically never instinctive, except where moral issues are concerned. It therefore follows, that the successful manager of current enterprise must be equipped with a well defined, scientifically balanced training which will permit him to seek out and self-educate himself on those elements which he does not now know, and on which he, as a public or private servant of a corporation, is morally, legally and financially obligated to inform himself.

The Tools and Vehicles of Evasion

When making an examination aimed at disclosing the degree of ultimate responsibility assumed by the management, it is always helpful to bear in mind those tools and vehicles of evasive action which are most frequently made use of, when things have gone wrong and someone has to produce a sacrificial goat.

The Charter

Let us consider first the charter of the company, or corporation, or government department, which presumably spells out the purpose or objectives and/or ultimate aims.

Most every schoolboy recalls one of the first great charters in history, i.e., the Magna Charta, forced on King John on England and designed to suppress his personal tyranny. While it is true that this charter transferred John's despotic power in large extent to a committee of Barons, it nevertheless spread the base and defined some areas of responsibility.

Through the subsequent ages, the practice of writing a charter for businesses, big and small, has persisted with probably none in quite so good repute as that which we know as the American Constitution and Bill of Rights. At no time in the history of mankind has any charter so adequately defined rights and responsibilities for a group of people, the Fifth Amendment notwithstanding.

The avoidance of provision of a written charter as a sheet anchor for the British constitution has only been possible in an orderly community by the availability of close knit tradition and an almost universal respect for the law of the land. However, the obvious decline in the power and prestige of Great Britain, during the last forty years, can, in many of its phases, be traced to the recalcitrance of dependencies and people in Colonial status who refuse to continue their total allegiance on verbal assurances that everything would be all right, but with nothing in writing to define what "all right" means. Verbal assurances were, in large measure, effective when given by people of honorable intent a century ago, but at that time the degree of illiteracy probably exceeded 60% for the population, whereas today the figures are reversed, and in most of these places illiteracy is well below 30%.

It is a *sine qua non* that those who can read and write, instinctively feel the need of something to read, and

verbal assurances, unsupported by a piece of readable, authoritative paper, leave the kind of void which makes for trouble.

If we follow the line of argument down to the last unit of communal life, i.e., the family, no further argument seems entertainable when we consider the mother's right to her marriage certificate.

The Organization Chart

This imposing looking document is a necessary tool for efficient operation in an age of rapid change. In wordless fashion it settles arguments as to who is in charge of what, and when properly executed, it is a desirable and utterly necessary appendage to the Constitution.

There are, however, a great many people who deride the utility and practicality of an organization chart, but it is safe to say that this derision stems from one or two basic motives, i.e., a desire to profit by a disorganization, or to indifference. It is always a fair question to ask when confusion prevails—"who profits by this confusion?" —and not an unknown offender in this regard is the man in charge who is thereby permitted to pin his own failures and shortcomings on to his subordinate's shoulders, or as is more commonly the case, to deny recognition in the form of compensation to someone who is carrying an uncommonly heavy but undefined and unspecified workload not locatable on the organization chart.

Spelled out in the simplest language, avoidance of provision of an adequate organization chart means that management mistakenly thinks it is profiting by the ensuing and inevitable confusion.

Job Descriptions

It was undoubtedly demands for job definition by the trades unions which forced the issue on writing job descriptions, and the practice has spread until it has become almost a national pastime. When this job description is done with simple, direct honesty, and with all ambiguity either avoided or weeded out, the job description is the natural counterpart of the organization chart. However, in large organizations, equipped with personnel departments, staffed by people unable or unwilling to understand the technicalities of the business, the opportunities for the preparation and acceptance of phony job descriptions are legion, and when unchecked the practice can develop into a reprehensible racket.

Who, then, must shoulder the blame for such a state of affairs? None other than the big boss himself. Tolerance of an obvious intellectual dishonesty in any part of the business structure can be and often is the one bad apple which will rot the barrel if permitted to go unchecked, and just as a professed ignorance of the law is no excuse for its non-fulfillment, so with equal logic is tolerance of an inflated job description formula equally a matter of neglect of obvious duty.

Ambiguities in Specifications

Just as in the case of false or inflated job descriptions, so in equal measure is the issuance of ambiguous specifications a matter calling for prompt correction. Practically everything in this life can be defined within reasonable and acceptable tolerances, whether it be a promised delivery date, a dimension on a shaft, the efficiency of an electrical conductor, or the amount of power to be delivered by a turbine. Inadequacy in defininings specifications leads automatically to poor acceptance tests and worthless certifications.

Whose job is it to see that specifications are adequate?—no one other than the big boss himself. True, he can and,

in fact must, delegate his authority; otherwise how could he insure that all the supervisory jobs be accomplished? When failure to accomplish the assigned mission stands stark naked for all to see and condemn, who, but the titular head of the organization, must shoulder the responsibility?

The Engineer cannot bury his mistakes

The bridge which totters in the wind, the locomotive which will not pull its specified load, the ship which will not make its designed speed, the boiler which will not deliver its rated power, the lathe which will not turn out its accurate work; all these things stand out like sore thumbs and are recognized for what they are. Truly the engineer is on the spot. Unlike the unsuccessful lawyer who burns his papers and retires to Florida, unlike the poor doctor who plants the customers in the cemetery, and unlike the dozens of other professional people who deal in relative intangibles, the engineer must so manage his affairs that if his reputation as a good workman is to be sustained, he cannot have present too many of these monumental white elephants. In addition to his engineering training, the engineer must be a manager of great capacity, and it is for whatever benefit he can derive from it, that this paper on Management Concepts is dedicated.

That which is needed

In this day and age many and varied and often quite subtle, are the attacks on the concept of discipline. It would seem at times that our civilization, having advanced so rapidly in the field of mechanization expressed in terms of lightened human labor, that the humans, having freed themselves of this burden, now seek to free themselves of their patent personal responsibilities.

There are many lessons to be learned from that next to the oldest profession, the profession of arms, wherein it has been demonstrated through countless ages, that only through the medium of acceptable discipline can the will of the mastermind be exercised, and victory achieved.

What, then, is the parallel? Simply this—the root of a great many of our managerial troubles lies in the lack of industrial discipline which, in essence, must spring from the top echelon of management.

This is not the kind of discipline which is promulgated at every turn by rules and regulations, necessary though they be in minimum workable volume, but that brand of discipline which manifests itself in continuous application to the job during prescribed hours of work; also in that inwardly personally imposed variety, which eschews morale breaking, special privileges obviously at odds with the decor of the organization.

In the Services, it is the disciplined regiment which is the happiest and most effective in action. The same is true for the taut ship where every man aboard has his job spelled out for him and knows that he will be promptly called to account if he fails in his duty.

So in the factory, or the industrial plant, private or public, the matter of discipline can be summed up as a simple system of accountability, a system which automatically discloses waste and inefficiency of any kind and lays bare for all to behold the fact that there is a tooth in the industrial gearing which is cracked, broken or missing.

The good manager has a clean desk and a curriculum so ordered that he has plenty of time to supervise his industrial machine. In essence, he is the mechanic with the eagle eye, the mental oil can, and the fund of good advice available to each and every member

of his team. This manager's clean desk, his open office door, also his quiet, orderly staff are the trademarks of things which have made American industry dominant in practically every market which it has entered.

This efficient manager has delegated practically all of his executive duties to the appropriate officer in the line of command, to the point where he, himself, is the living embodiment of "management by the rule of exceptions," the exception, of course, being when something new and different enters the field, whether it be the prospect of a new and different contract, or a new form of indiscipline by some member of his crew.

In an organization which could, with justice, be assumed to have reached a state of reasonable maturity, the acknowledged turning point which marked the attainment of maturity was the day the boss was able to exercise his managerial duties through this rule of exception.

During formative stages in an organization it is seldom or never possible for the senior official to do other than roll up his sleeves and get down to workload brass tacks with every division of the business. However, if, during these formative days, the foundation be not laid for the orderly and progressive delegation, of authority to make decisions down the line, then nothing but endless confusion can result.

It is the prime responsibility of top management to define policy, and this written statement of policy, and in some cases procedure, constitutes the "charter" for each division of operations.

Armed with a statement of the company's policy and such minimum guidance as is necessary in regard to procedures, the divisional or departmental manager is equipped to play his part as a member of the production team, whether that production be engineering drawings, the processing of work through the shops, the company's participation in recreational activities, or the direction and control of the company's negotiation with the unions representing the workmen in the plant.

Difficult, you say—but never too difficult. The general managers who qualify, are those who earn the big money. Those who do not, soon fall victims to that form of cannibalization which, for want of a better name, we describe as nature taking its course.

The president and general manager of the largest railroad in the world successfully and profitably operates his company on the information in six dead-accurate summary reports which are on his desk by 0900 each morning. The message in each of these reports define his workload for that day. Some flash a red light and insistently demand prompt corrective action — most are green — others amber — say proceed with caution, but with it all, there is a plan — the boss knows where he is heading — all the time — and so does the team.

FIFTY YEARS OF FLYING PROGRESS

ACKKNOWLEDGEMENT

This article, by Grover Loening, was published in the December 1953 issue of the "Journal of The Franklin Institute."

Fifty years is, actually, not a very long time in the development of one of humanity's greatest means of transportation, but when we stop to appraise aircraft development in this period, and compare the original first machine to fly successfully, the Wright "Kitty Hawk," with our latest supersonic airplanes, we see the most striking and convincing progress in speed. A gain of well over 1200 miles an hour in 50 years would average out at 24 miles an hour faster each year. Curiously enough, this is approximately the rate of progress that actually did take place for several years after 1909. The Wright Model B at 40 miles an hour and the original Curtiss at about the same speed in 1909 were outclassed in 1910 when Leblanc on a Bleriot raised the record to 68 miles an hour. In 1911 the Nieuport did 82 miles an hour. In 1912 the Deperdussin raised this to 108. And so on through the years. The official records today are of course not yet inclusive of the actual speeds made by supersonic aircraft due to the secrecy that is maintained. But this much we can say—that if the unfailing record of the years continues, by the year 2003 aircraft will be flying at 2400 miles an hour! While it is true that the present supersonic aircraft are merely research airplanes of very small load capacity, more practical load-carrying airplanes quickly catch up with the initial record-breaker. For example, when subsonic jet aircraft single-seater fighters of recent British and American development, like the Meteors and the Lockheed Shooting Stars, arrived at the 500 mile-an-hour class, it was not very long before the Comet airliner carrying over 36 passengers was doing the same thing. So it will only be a short few years before load-carrying aircraft will be equalling and exceeding the speed of the present supersonic airplanes.

SLOWER LANDING SPEED

While speed gain is the outstanding successful evidence of our great progress these 50 years, the lack of attainment of low speed for landing is our outstanding failure. The very early Wright airplanes had so much parasite drag resistance, so much area with accompanying skin friction, and yet so light a total weight that they could literally be almost dived at a landing spot and then flared out. So, it was possible for landings to be made in very restricted areas with high obstacles. One of the outstanding feats

in this category was when Harry Atwood landed his Wright Model B on the south lawn of the White House in 1912.

Early Wright, Curtiss, and Bleriot exhibition teams flew constantly and with great ease off race tracks and even ball parks throughout those exciting exhibition years (1909 to the beginning of the First World War)—when the public was being entertained by aircraft to so great a degree, and when the real business of the industry was chiefly building for exhibition work and racing and only in a minor way for military usage. Of course the wing loadings of aircraft in those days was around two to four pounds a square foot for biplanes and three to six pounds a square foot for monoplanes, and the light loading had much to do with this early small-field-ability. But we have a great loss in aircraft value as of today in having failed to maintain this ability, and failing to such an alarming extent that 10,000-foot runways are now considered too short. Landing speeds of 200 miles an hour are seriously talked of, and the aircraft engineering fraternity, in too large measure, goes blithely on its way ignoring the heavy burden on practical progress and usage that aircraft development is placing on itself by not realizing that we have failed miserably in advancing the technique of slower landing speeds and shorter field usage. The Wrights showed a way we seem loath to follow.

To be sure, there has been some development of high lift devices, a very useful development of wing flaps and air brakes without which even the present fast airplanes would be so hopelessly handicapped that there wouldn't be enough real estate around to take care of them at all. Also, of course, we have the development of the helicopter of recent years to somewhat offset our failing in extending downward the speed range of fixed-wing aircraft. But the helicopter has the very serious deficiency of being a slow aircraft—very useful to be sure, but by no means the final answer until it can carry loads very much faster.

The economics of air transport, particularly in the requirements for such large landing areas (which, while many are built with government funds, are nevertheless a burden either to the taxpayer or the operator who pays a landing fee), shows that these cannot possibly grow with the growth the aircraft usage should have in the coming years unless we reverse the trend and get busy now to reduce landing speeds every time that we also make an increase in the high speed.

Interestingly enough, one of the later activities of Orville Wright around 1923 to 1925, when he was more or less retired, was to spend a good deal of time testing in his wind tunnel the various series of flaps and high lift devices which are now exhibited at The Franklin Institute. The ordinary split flap was patented by Orville Wright in 1924, and very few people realize that he was the inventor of this device. The Guggenheim Aircraft Competition came along in 1929 and was designed to be a great stimulus to the progress of more useful and slower landing aircraft. At least two very advanced aircraft, the Curtiss Tanager and the Handley-Page, very convincingly demonstrated their short-field abilities on both landing and take-off, and yet for almost ten years the aeronautical engineering fraternity only took a slight interest in what these demonstrations had shown. The early development and progress of the Fowler Flap was also delayed and stretched out over many more years than was necessary by this curious blindness in judgment or delay in appreciation by aircraft engineers and their customers of the supreme necessity of doing everything to reduce landing speeds.

VERTICAL FLYING

At the present time it appears that this need in aircraft development is receiving an increasing amount of serious attention, and there are several areas in which activity may result in quite striking development. The term "vertical flying" is at last coming into serious use in technical discussions. Designs for vertical take-off merely on the basis of jet, rocket, or turbo-prop thrust being greater than the weight, are solutions that are actively being worked on. Then, too, there is a field of promise in a configuration using an "induced" high velocity flow over the wing by a disposition of jet engine intakes and exhaust to give an artificial flow in the slow-speed regime which would greatly increase the lift, even while standing still, greatly reduce the length of take-off and the landing speed, and yet be readily converted from "lift flow" to pure "thrust flow" for very high speed flying.

It was Henry Ford, Sr. who, when discussing aircraft design almost 30 years ago, criticized aircraft engineering very severely for failing to realize that aircraft would really not attain their full development until their power "was used to land with."

SPEED RANGE BY BETTER WING SECTIONS

During this first era of aviation progress, wing sections have been much improved in the range between high lift and low lift and low drag, but there is still much that could be achieved. Speed range (the ratio of high speed to landing speed) in the early first ten years of flying development was considered extremely good if it got as high as two-to-one. In the course of the ensuing 20 years due to improvement in wing sections and finally in the addition of wing flaps, slots, and other high lift developments, there has finally resulted a raising of the speed range to about six- or seven-to-one. In further development to come, our figures are somewhat obscured by having to pass through the sonic range. However, an interesting new development of the last few years which cannot yet be sufficiently appraised is the development of the Delta wing configuration. The range between low-speed, high-lift, and high-speed low-drag appears to be materially further extended with the Delta wing design.

There are other developmental areas in which the extension of the speed range to higher speeds for usefulness and to still lower speeds for practicality, are being worked on.

ASSISTED TAKE-OFF, AND SKIS

Only recently have we begun to hark back to one of the original conceptions of the Wrights.

The original 1903 Wright plane was launched into the air on a small cart riding on a rail with no assist to the take-off. This saved the expense of fixing a smooth field, and saved the weight of a landing gear. Later in their developments, particularly in the many 1905 flights, the Wrights introduced the use of the catapult to assist on the take-offs, and then eventually went to wheels. A long and painful development of landing gears followed through the ensuing 40 years, and finally today, interestingly enough, our

concepts are beginning to return to the original Wright conception, with the use of assistance in take-off by either catapult or rocket "jato" assist. Even additional jet engines of small sizes are now being contemplated to give an assist in take-off and when reversed to give a retarding influence on landing. So that we see at least a more determined struggle going on in the engineering development of aviation to compromise the requirement of the highest possible speed for utility with the lowest speed for practicality.

As to the utility of high speed in aircraft, history shows us that there is no question about this whatever. There is nothing more useless than a slow airplane, and the helicopter's slowness in cruising is a burden about its neck that must be removed quite soon in order to make this field really succeed in the long run. Once in the air free of obstacles, all the economics of air transport, all the characteristics so needed by the military, all the practical usefulness so needed by the individual owner, all bring success to aircraft development only if the item of ever-higher speed is included. And yet, as pointed out, these eminently promising prospects for great future development are hampered initially by the take-off and landing limitations that our present day airplanes require. As the realization of all this is at present dawning upon the brilliant engineers in the industry, we will see shortly—in fact are already seeing– a great deal more attention given to assisted take-offs and catapults. And when we look into this field we find some very surprising conditions.

For example, the Air Force (particularly in the Attack plane and Assault types of air operation), requires very short take-off and landing characteristics. And yet with all the development that the Navy has so successfully demonstrated in its catapult launching and deck landing hook, and wire-engaging retarding mechanisms, it seems only lately to have occurred to the Air Force of any nation to make these the landing systems that they should lay down at a front instead of worrying about long clear runways. If there was ever an argument for a "united" air force, it is this one. And yet if we had ever had a "united" air force, we probably never would have had the Carriers with their landing traps and their catapult take-offs.

Now several advanced designers are beginning to think in terms of fast aircraft of much lighter weight (because they carry no landing gear to speak of) that will take off on a field from either a catapult or a powered launching car and will land on simple skis that will have no extensive roll and no need for brakes that get too hot. And when we do this, it is interesting to see the 50-year cycle reverse itself. Fifty years later we return to the original concept of the Wrights.

WATER BASED AIRCRAFT

While the familiar concrete runway is accepted with a certain finality by everyone, the history of the development of aviation throws this into a considerable question. We have prospects, as indicated above, of developing characteristics in aircraft that will allow the fastest load-carrying kind to land more or less vertically in restricted areas. But we have also in the last few years the development of the jet engine, by which we have ceased to require the use of a propellor. And this has re-opened the entire question of whether we should not use water surfaces as the proper surfaces for aircraft to take off from. In 1907 the Wrights began to get the same

idea, and in preparation for some flying around Norfolk over a fleet review —that they were then contemplating —they began work on pontoons to carry their plane. But one of the earliest things they ran into right then was the difficult incompatibility of propeller tips and spray. And this necessity of the clearance of propellers from the water has plagued seaplane design ever since. It is the one item that has caused seaplanes always to be so ungainly, of greater head resistance, heavier, and because of these, at a disadvantage in comparison to land planes.

But with the advent of the jet engine all this changes. We have a new condition that finds water-based aircraft gaining advantages over land-based aircraft. The jet-engine seaplane does not need any great clearance dimension for propellers, merely a configuration in which the jet intake is reasonably free of spray. The jet exhaust is no problem at all. And as a result, the configuration of a jet-driven water-based airplane cannot only be fully as streamlined as a land airplane, but is lighter in weight because of not having to carry the heavy landing gear—so difficult to stow anyhow in the thin wings required by high speed. And accompanying this new state of affairs we find today that the development of skis for water landing is achieving a practicality that is very evident. This leads to endowing airplanes with the ability to land and take off rough water to a degree that we have never conceived possible because the skis can be sprung—and incidentally, are very easily folded up into a streamlined body. Demonstrations of the success of this concept have been given in a most convincing manner by the first public flights of Earl Osborn's Edo ski amphibian, the Convair Sea Dart XF2Y-1, and the All-American ski-equipped land planes.

Lest we get too set in our ways of thinking that airplane usage means land field usage, let us look back into history for a moment and realize that there were two or three different eras in which the speed records of the world could only be won by airplanes that were launched off the water. This was importantly emphasized in the Schneider Cup races, the international events that were held in the late 1920's and early 1930's, in which the speed of land planes was far outclassed by seaplanes—only because of the ability to take off and land on the water surface under conditions of loading and distance that no land area would permit of. Very much the same thing exists today. If our wing sections and high-lift devices were still to limit us to a speed range of somewhere around 6 or 7 to 1 between high speed and landing speed, and if we wished to build the very fastest airplane to win a race from a surface take-off (not air-launching), we should lay down a design that would land and take off at 300 miles an hour and would achieve 1800 to 2000 miles an hour in the air. This admittedly would be a difficult job on a land field, non-catapult take-off. But interestingly enough, it would not be difficult on a water-ski seaplane take-off and landing. The only reason that this concept is not as sure-fire as it would have been 25 years ago is that a plane achieving any such high velocity would probably have a thrust greater than the weight and therefore could take off vertically. But it would still have to land, and the vertical take-off would be considerably easier on the water and much less dusty for the observers. We can only sum up this aspect of our 50 years of progress by pointing out that there is still much thinking, devising, and developing to be done on the fundamental problem of how we take off from the earth and how we get back to it.

WING STRUCTURES

The configuration of the wing structures of aircraft from the original Pratt truss Wright biplane, has gone through quite a cycle of development, be-fogged by an enormous amount of prejudice, misunderstanding, stubbornness, and lack of sound engineering foresight. Instead of facing the facts of efficient lift and how it could best be obtained, aviators and constructors from the very start to well around into the 1930's got themselves wound up into so much argument as to the relative merit of biplanes and monoplanes that it took no less than 40 years to clear up what was very obvious from the beginning. The reason the Wrights went to the biplane was perfectly sound and had to do with the question of bracing, of weight limitations, and of a good deal of engineering convenience. But just as soon as air development embraced higher speeds and more power, the reason for the biplane vanished. But—the biplane did not! And all along the era from 1918 for over a score of years thereafter, there still was a stubborn persistence of the biplane form of wing structure. This finally, however, gave way to what we have today—no biplanes in the air in the world excepting a few old-time crates towing advertising banners! This author can derive a very distinct gratification from history on this point because in 1918, convinced of the correctness of the monoplane type, he was almost alone in this country in advocating it, and found the acceptance of the monoplane by the aircraft industry's customers so difficult and so surrounded with prejudice that in 1923 he was forced to make the Loening Amphibian a biplane for no other reason than to sell it. The greater lift of the monoplane due to the lack of interference of one wing with another, the considerably lower head resistance, and the lighter weight, won out in the end over the fancied objections that had been harped upon for so long. The untenable anti-monoplane sales talk was that a monoplane was unstable, structurally weak, and too "tricky" in maneuvers. The simplicity of the monoplane structure insured its survival—particularly of the type, referred to above, with a simple strut bracing, which type 20 years later came into very general usage and still is seen in the Cessnas, Cubs, Beavers, etc. Of course, eventually the struts have been superseded by the cantilever monoplane structure that is now so nearly universal. A quotation is given here from a treatise on this subject by the author, "Revival of the Monoplane," written in 1919, which perhaps has a message to give:

"Aeroplane designing is merely a series of extraordinary compromises that have to be hit upon with a rare judgment because in general all aeroplane features fight each other—weight needed for strength reduces flying performances, roominess for convenience requires a sacrifice to head resistance, etc., so that the competent engineer must constantly balance these opposing features. If he brings out a triplane, let us say, just for the sake of making it a triplane because other machines are biplanes, without having very clear and logical reasons for doing so, he fails in his true mission. The ideal features that we are looking for in the aeroplane structure itself are (1) light weight—the most important of all—(2) the combination on a machine of stability (meaning ability of the plane to stay where it is put along its course), combined with easy controllability (which means a quick, positive response to all controls)—this is perhaps the hardest feature to develop in a new plane; (3) the desirability of simplic-

ity of construction, which almost always bring light weight with it, and finally (4) we seek a low head resistance, obviously, so as to get our best performances.

No matter what purpose an aeroplane is designed for, be it a large bomber or a small scout, a waste of weight is little short of criminal in aeroplane design, and complication, it is well known, is usually evidence of bad engineering. In fact, the whole essence of really good engineering is simplicity."

But it took the aircraft industry almost 30 years to learn the above lessons in the configuration of wing structures. And yet such lessons and precepts were exactly what Orville Wright taught.

ENGINE LOCATION

Engine location was, of course, another problem of configuration for aircraft designers which followed prejudices and fashion a good deal more than sound engineering sense should have allowed in these 50 years. The pusher installations at the beginning were convenient structurally and supposedly more efficient. In the case of the single propeller direct drive installations like Curtiss, this was later to be proven wrong, because the efficiency lost by the added resistance of the faster tractor slip stream on the fuselage was regained by added lift on the wings. This had apparently been appreciated much earlier in Europe than in this country, because in the 1907 to 1914 era the development of the tractor fuselage airplane in Europe was far ahead of what we had in this country. It is remarkable that in the case of both Wright and Curtiss we persisted so long in this unsatisfactory pusher type because, of course, of the great danger in many minor accidents resulting in fatalities. The engine often fell out on the crew, due to the light weight structures that were then needed, in order to get into the air at all. Probably one of the reasons for this "pusher" persistence was that for exhibition flying there was great merit in the public being able to see the aviator completely exposed, sitting on his perch at the leading edge of the wing with no protection from the wind whatever. Even Orville Wright succumbed to the tractor configuration when in 1916 he brought out his Model H enclosed fuselage tractor-type which Howard Rinehart flew around the country so successully. In seaplanes, the pusher type quickly succumbed because of the spray thrown into the propeller, and the tractor type was even more advantageous there. Then, of course, as we progressed, we got to multi-motored aircraft with the engines at first mounted between the biplane wings (a most inefficient configuration), and then finally with the engines as we see them today mounted integral on the monoplane wing. It is interesting to note that this efficient, correct, and simple type has survived as an element of configuration on aircraft for almost 30 years. In this country, of course, the early Boeing 247-D and the Martin bombers of the early 1930's were the eminently successful forerunners of this later-to-become-universal twin-engine configuration. During the arrival at this final type we also went through a tri-motor period, notably the ubiquitous Ford tri-motor and the Fokker. But this type did not last except for the Fords, which of course, were more widely used and probably one of the most successful airplanes in history.

STABILITY AND CONTROLS

Fifty years have done much to the airplane's control surface, stability, and tail configuration. Re-examining the early Wright plane from the standpoint of our present-day knowledge, we first must pay tribute to the acrobatic balancing skill that they had to have in order to keep the airplane flying straight. The "Kitty Hawk" was controllable all right, but completely devoid of any natural stability. This applied also to the early Curtiss planes. And while on the subject of controls and stability, we should make it clear that it was in this area that the Wright invention really counted so effectively.

To begin with, the Wrights and Spratt who aided them, made a discovery in their early gliding experiments for which ample credit is never given. They were definitely and distinctly the first ones in the art, here or in Europe (and this included Lilienthal and of course Langley), who found out and verified by test that the center of pressure on a curved surface moves *backwards* when the angle of incidence is decreased. All other experimenters had thought that the center of pressure acted as it did on flat plates and moved forward. The Wrights also verified this in their wind tunnel experiments, and incidentally, Wilbur Wright mentions this in his famous paper before the Western Society of Engineers in 1901. Center of pressure location enters with fundamental importance into the question of stability, because the knowledge of this enabled the Wrights to balance their plane correctly and to arrange their longitudinal up-and-down control to operate properly. Then, of course, the basic Wright invention on which they received their patent was their lateral control of roll. They put into practice the realization that up-and-down control and side-to-side control by rudder were not enough for successful flying, and that a third control was needed to balance laterally in roll.

The Wrights first incorporated lateral control in their airplanes by the well-known lateral twisting or warping of the wings. When they did this, of course, the side that had the greater angle of incidence, and would therefore raise up, would at the same time have a greater drag and therefore would require compensating rudder action. This was where the Wrights combined the directional yaw and the lateral roll control into one movement, although in later types of other constructors like Curtiss, pilots learned to do this as part of their training. As we progressed into the tractor type with a fuselage, the fuselage gave considerable directional fin area, and the very earliest enclosed fuselage types like the Nieuport had a quite low small balanced rudder at the end, so that they still required a great deal of coordinating of the lateral and directional controls. But as our 50 years progress, we find the combined rudder and fin area becoming larger and higher, and finally in the modern airplane of today so high that much lateral balance is obtained from the rudder and fin alone, and the necessity for coordination on a really good modern airplane has more or less ceased to exist. We have excellent planes that turn very nicely on ailerons and equally good ones that are corrected laterally on fin and rudder alone. Tail length has also gone through an ever-lengthening development. The "Kitty Hawk" was very short tailed—of course it had the front elevator, a questionably stable layout, which was in short order replaced by a horizontal tail in the rear with a much greater lever arm. But as we go down through the years we find tails of good aircraft becoming longer and longer, and larger and

higher, and as we are about to wonder when this will stop, along comes the Delta plane design and brings us abruptly to a halt. Of course modern wing sections have been developed that have a very much smaller and more stable center of pressure movement. And this makes the shorter Delta wing configuration much more feasible. The Delta wing still looks as if it will continue to have large fin and rudder areas with considerable leverage around the center of gravity.

There have been two body configuration developments through these years slightly different from the natural growth of the covered fuselage into the enclosed cabin, and into the large, roomy interior bodies of the airliners of today. One, of course, is the Burnelli and Northrup projects of carrying the loads in a very thick wing. In the case of the Northrup, this was carried even further into the "flying wing" type where there was no tail at all. But as the "flying wing" developed, what amounted to tails began to be added to the wing tips, giving lateral and directional control leverage around the center of gravity, introducing the complication of added surfaces and the weight of controls and their stresses. Whether for this or other reasons, the tailless airplane has not survived, and not even in the case of the Delta wing can we consider that it has survived because the successful Deltas have such large fin and rudder tails. The other differing configuration is the twin boom holding tail structures such as in the Fairchild Packet and the new "Nord Atlas" in France. There is a sound reason for this twin boom design that has nothing to do with either controls or stability. It is the excellent way in which this configuration allows for a cargo-carrying body with accessible doors very conveniently arranged for loading or parachute-load dropping. The excellence of this configuration as being sound is all the more accented when one contemplates other cargo types that have a large swept-up fuselage with a very high tail, the strength of which fuselage is tremendously weakened by the cutting out of a large door right in the center where torsional strength is needed. So that to resist tail flutter and carry the high tail twisting loads, a very heavy fuselage framing is needed to make up for the door hole weakening.

As soon as the wing warping lateral control system used by the Wrights and by Bleriot disclosed how it weakened the wing structure and what heavy loads it put on the control system, it gave way to the use at first of separate surfaces in between the two wings like the early Curtiss Ailerons and the ailerons that Glenn Martin mounted on his first and very successful tractor airplane. In the first few years of flying development, even the elevators and the rudders were quite widely used in a balanced single surface form. Then when these gave way to the fixed stabilizer and trailing elevator and to the fixed fin and trailing rudder, it was not long—about 1909—before Moore-Brabizon in England, Farman in France and several others both in Europe and America obtained their lateral control from hinged flaps cut out of the wing tip. These controls have survived ever since, and had every right to continue to survive as they were eminently correct and practical and were easily modified to have mass or aerodynamic balances so that they could grow to large size and still be workable.

However, as soon as we entered the trans-sonic and supersonic area of flight, aircraft controls by movable hinged surface areas became open to a great deal of question. Lateral control had already been toyed with in the form of spoilers that would reduce the lift on one side only. But the problem of control in the supersonic region still

remains. It is fairly certain now that control by hinged flap is apt to be superseded by something else.

Although we are principally concerned here with our 50 years of fixed wing aircraft development, control and stability problems are plaguing helicopter development to a very considerable degree. It may be that helicopters will have to go to a three-rotor system giving three points of control like the two wings and the fixed tail of the Wright airplane and then merely vary the thrust of the rotors against each other to get any combination of control forces around the three axes.

LANDING GEARS

The landing gears of aircraft have gone through a complete cycle in these 50 years. The Wrights started with skids alone, and the hottest new designs of aircraft today again look like skids alone. The story of this metamorphosis is about like this: The Wrights started with skids alone, because their feeble craft could not carry the added weight of wheels, nor had it enough horsepower to overcome the wheel friction, and the landing on skis was simple and effective and short. Then, as their power grew greater and the Model B developed from the original 12-horsepower to the 30-horsepower class and their power-loading went down to 40 pounds a horsepower, wheels were feasible and were merely added to the then-existing skids. Then for many years landing gears of airplanes all over the world, with one outstanding exception, were always a combination of wheels and skids, the theory being that if the wheels failed, the skids would save the works. The one outstanding exception was Bleriot in France who never had any use for skids at all. In those early days we soon discovered that many a landing resulted in an accident, not at all because the wheels failed, but because the skids broke, dug into the ground, and turned the airplane over. So some of us here proposed and put into effect the simple 2-wheel and tail skid landing gear which was first introduced at North Island by the author in 1913 and incorporated with a great saving in weight on several then-existing Army training planes. By placing the wheels reasonably forward, nosing-over tendencies were avoided, skids ceased to break, and this type of landing gear became standard for the next 30 years. Then there started to come into wider usage the presently widely used 3-wheel gear with nose wheel forward and the two main wheels aft of the center of gravity. This "level" type is of course very practical and effective and will continue to last for some time. But meanwhile, advances continue, and the next step in landing gears is going to be either a catapult track or a dolly truck for take-off with the airplane equipped only with skids to land on. To be sure, these skids will wear out after many landings, but so do tires. By doing away with the wheel and the tire we not only shorten the landing, but we do away with complicated braking systems and with a heavy weight of wheels and with what is even more serious, the difficulty of stowing wheels in the thin wings that our higher speed regimes now demand. Of course there is another advantage —the ski landing gear can take off the water, can land on snow, can land on mud, and if we finally do get to vertical take-off aircraft as we are very likely to soon in great quantities, the wheel gear will disappear excepting for small rollers for convenience in handling on the ground. And thus we

will get back to the ski-equipped airplane that the Wrights started with 50 years ago.

During the landing gear development of this era, it is surprising to note how tardy and stubborn and backward most aircraft constructors were in adopting retractible landing gear configurations to improve their performance. It is safe to say that had it not been for the development of the amphibian which showed the ease with which landing gears could be retracted, the progress in this area would have been even slower.

POWER PLANT FORMS

The types of engine forms during this period have gone through equally ever-changing development until finally we get to the jet engine which, of course, is a totally different departure. Propellers also have been the subject of much development since the early Wright days, and we should therefore consider them jointly as the effective power plant. The Wright's original solution was little less than inspired. With all the knowledge that we have today of propellers and of power plants, given the materials of construction, the technique available, and methods of manufacture, the Wright's solution for turning BTU's of gasoline into effective driving thrust for flying could not be improved upon. The Wrights approached their propeller design from the correct standpoint of considering their blades rotating airfoils, and their calculations and method of design are still today an outstanding tribute to their engineering and scientific abilities. In this designing region they really had very little to go on, excepting some marine screw propeller theory, much of which they quickly discarded. While they of course had a power loss between the engine and the propellers due to the chain drives and sprockets and extra shaft bearing frictions, this was all more than made up for by the fact that their two large propellers were giving a very high order of efficiency at their flight speed of 30-40 miles an hour. This they could never have obtained if there had been only one little direct drive propeller on their little 12-horsepower engine. Also, the Wrights had the good sense to eliminate torque as an added complication to their stability and control problems by having their propellers turn in opposite directions. As the years grew on, however, and the power of engines became ever greater—and the power of controls also became ever greater—torque was not too great a problem other than on take-off. But from the efficiency standpoint, the value of geared-down, large-diameter propellers is becoming increasingly impressed upon us even today by such advanced planes as the Helioplane of Koppen and Bollinger. The slow progress of including in propellers the added efficiency item of variable pitch, took years to get into the picture because of the same strange unwillingness of aircraft engineers to move, even though the signposts of where progress is leading are sometimes so clear. The propeller construction of the Wrights was of wood with fabric covering to protect the wood from splitting too easily when hit with stones from a field. These wooden propellers were soon found to suffer from humidity and other variations so that they were gradually succeeded by metal construction, first of a steel hub with aluminum blades, and then steel blades, and of late some new plastic developments of great interest.

Engines themselves started out in a flat pattern with the Wrights. And

then they put their four cylinders into an upright model with the crankshaft low, and in Europe there was an early start on the first radial air-cooled engine. Then came the tremendously successful Gnome rotary engine, and then both in Europe and in America the further tremendous development of the large radial air-cooled. During the development in use of the water-cooled upright engine like the Liberty, it became increasingly apparent that whereas the Wrights had good reason for the upright engine in order to have their chain drive mount on the wing, the later water-cooled tractor types for aircraft should have started out right then and there as inverted engines with the crankshaft high, in order to give maximum propeller clearance for minimum body height. And looking back at this era, it is very likely that this would have been the case had automobile engineers not been so intimately identified with water-cooled aircraft engine development.

In radiator cooling for water-cooled engines, our 50-year era had a problem that was never properly solved excepting by the advent of the air-cooled engine. Even in war planes the liquid-cooled engine had its greatest disadvantage in the ease with which one bullet could wreck all by hitting the radiator, whereas an air-cooled engine could have several cylinders beaten up without having to stop at once. Radiators through these years assumed all manners of shapes, sizes, and configurations. They were placed in front of the engine, behind the engine, above the engine, slung underneath, formed into wing surface contours, and so on. The Wrights started out with a simple vertical combination of standpipes that had a large cooling area for the water volume and—a very important item—a large gravity head over the water pump. The weight of water cooling was mitigated somewhat in later years by the use of chemicals for cooling, but the extra plumbing and the extra weight and the extra drag always remained. And there were many sighs of relief when air-cooled engines came into such great usage, just as there are sighs of relief now that we enter into the jet era, with a simple, easy-to-install power plant.

MATERIALS OF CONSTRUCTION

The materials used in construction of aircraft have, of course, varied considerably down through the years. At first silver spruce was the backbone of aircraft construction used by the Wrights and others in wing spars, struts, ribs, etc., with ash used for the skids as it was a much harder wood. But the generally unsatisfactory nature of wood, the difficulty of getting homogeneous pieces of the same weight and even of the same strength that could be relied on, the many kinds of weather and humidity effects that would affect the strength or alignment of the structure, were all headaches that quite naturally led, both in Europe and in this country, to a search for metal construction. At first this was considered altogether too heavy. But it was not long before very thin high alloy steel tubings gave a weight ratio to their strength that was satisfactory. While at first the joints were made with fittings and then later were brazed and soldered, the Fokker type of welded tube construction came into wide usage, particularly in the framework of fuselage and tail surfaces. At first wing surfaces were covered with oiled silk or rubberized fabric, both of them most unsatisfactory materials subject to tension variations under different weather conditions.

This was followed by the doped linen or cotton era. Then plywood began to enter the field particularly in some very fine workmanship samples such as the beautiful Antoinette monoplane built in France. And whereas plywood was used for the covering of fuselages such as introduced in the monocoque by Deperdussin in 1912, it was not until towards the end of the First World War that Fokker appeared with cantilever wings of thick section with wooden beams and plywood covering that took the torsional strains. This was a good deal of an innovation in aircraft structures and pointed unerringly towards the future, but at the time was not adopted very widely.

These wooden cantilever plywood wings were of course also subject to the weathering effects on wood—the drying out in the sun, the inability to stand too much moisture, the questionable strength of glued joints subjected to extensive weathering or vibrations. The forecast of things to come on aircraft structures was given by the Junkers all-metal cantilever wing monoplane which made in Germany what was later to be a world-wide appearance, around 1921. This step was marking the final death knell of the wood-frame, wire-braced box kite of the Wrights and their later contemporaries like Farman in Europe. But for a period of almost 20 years the aircraft industry still persisted, and their customers still insisted on their building this unsatisfactory type of aircraft structure, making it a long process before the Junkers of 1921 became the Strato-Clipper of 1951.

The prejudice against aluminum in structural parts of aircraft was very great in the early 1920's. The aluminum alloy Dural was relatively new, and faith in its characteristic of having the strength of steel for one-third of the weight was slow in taking hold. But gradually it crept into more and more extended use until finally in the vast production era of World War II, all-metal Dural riveted and welded aircraft construction proved itself out in the tool room, in the production line, and in combat, so that it became the universal method of building aircraft. This type of construction is threatened today by the advent of magnesium on the one hand, still lighter and with many qualities in its favor, with several different kinds of glass and plastic resin materials that have excellent qualities to recommend them for aircraft structures, and finally by the advent of that great new metal, titanium, which has all the qualities that we need excepting that there is not enough of it. There is no doubt that the field of alloy metals for aircraft will, from here on out, be subjected to great improvements and modifications which might even include some mutation of crystalline structures by virtue of atomic radiation or isotope application. Since we have been at this fundamental of light metals of great strength for aircraft work only 30 years, we can look forward to as great changes in the next two or three decades as we have had in the past.

CONCLUSION

Is the development from the Wright "Kitty Hawk" to the airplane of today likely to continue to bring as great a change in the airplane of tomorrow? Supersonic flight is bringing with it the problem of heat which will vitally affect the structure of aircraft. Many accompanying developments in science that have been coordinated into our aircraft progress such as electronics and gyroscopics will continue to grow greatly in importance, so much so that we are entering an era where tricky flying qualities requiring an expert

acrobatic aviator to handle will give way to automatic devices. These will reduce the fastest flying, as far as the pilot is concerned, to such simplicity that an older man with poor eyesight could handle the aircraft fully as well as the present stunt pilot can. Autopilot and automatic stability machinery can fly far more accurately than even the best pilot can do.

Then we have the era of vertical rising of aircraft coming in where even the fastest design will cease to need these expensive enormous landing fields. We will recognize that flying consists of two regimes —the take-off and landing in a practical manner near the objective, and then the highest possible speed between terminals.

One item in our development that has been more or less ignored these 50 years and is plaguing us now very greatly, is the suppression of the outrageous noise of modern aircraft. The piston-engine airplanes are bad enough, but the present jet configurations are even worse. And unless we can overcome this, the vast development of the aircraft field that awaits it—particularly in the private vehicle field—will be greatly restricted.

The concept of the Wrights has grown to full stature. It has endowed mankind with a mobility that was undreamed of. To be sure, it has not changed the difficult nature of human nature, but it has promise,—by virtue of its very terrible potentialities in war,—of forcing the world to find more peaceful means of getting along together. So that after all, the Wrights' original hope that this invention would not always be dedicated to war may finally turn out to be happily resolved by its more prosaic success and wide usage for peace.

THE STRESSES, STRAIN AND DISPLACEMENTS IN A SPHERE

IRVING GRANET

THE AUTHOR

Born July 2, 1924, in Brooklyn. Attended Brooklyn Technical High School and received Bachelor of Mechanical Engineering Degree from Cooper Union in 1944. Served two years with Air Corps overseas as Flight Engineer. Employed 1944-45 on Navy Torpedo project as project engineer on stress and vibration studies. Since 1947, employed as project engineer, Research Department, Foster Wheeler Corporation. In June 1948 received Master of Mechanical Engineering Degree from Polytechnic Institute of Brooklyn and in 1949 received Professional Engineers License in New York. At present going to Brooklyn Poly for Doctorate degree and also teaching Thermodynamics in the evening session. Has published several articles on properties of gases.

Recent developments in the use of high pressure fluids for such applications as catapaults, accumulators, boilers and chemical processes have focused attention on the sphere as a suitable containing vessel. While the solution for the stresses in such a vessel may be found in the classic works of Timoshenko[1] and Love[2], the solutions for the strains and displacements can only be found with some difficulty. In order to give the complete solution to the problem of the spherical shell and at the same time illustrate the method of attack, we shall deal with the problem of internal pressure only. The limitations placed upon the material are that the material be perfectly homogeneous and follow Hook's law. The approach to this type of problem is relatively easy but the details are involved and tedious.

We first consider the stress system given in Figure 1. From the consideration that the inner and outer surfaces

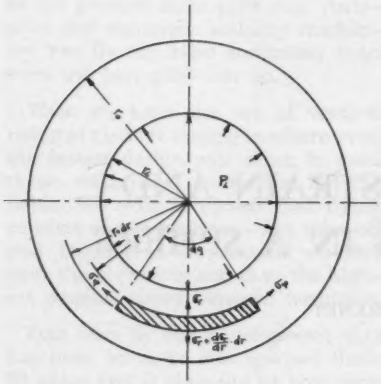


Figure 1

are concentric with the center at the origin it is immediately evident that only normal stresses need be considered. The equilibrium equation for the case of centric symmetry is derived in Appendix A as:

$$\frac{d\sigma_r}{dr} + \frac{2}{r}(\sigma_\gamma - \sigma_\phi) = o \qquad (1)$$

In addition to equation 1 it is necessary to have the stress components as functions of the strain components and the elastic properties of the material. The necessary relations are derived in Appendix B and are given as equations 2 and 3 below.

$$\sigma_r = \lambda[2\epsilon_\phi + \epsilon_r] + 2G\epsilon_r \qquad (2)$$

$$\sigma_\phi = \lambda[2\epsilon_\phi + \epsilon_r] + 2G\epsilon_\phi \qquad (3)$$

Since we are dealing with the complete solution, and the stresses have been expressed in terms of the strains, it is now only necessary to introduce a further set of equations. These equations express the displacement in terms of the strain components in polar coordinates. It is only necessary in the derivation to note that for the case of centric symmetry the shearing strain is zero. With this in mind, equations 4 and 5 follow.

$$\epsilon_r = \frac{dU}{dr} \qquad (4)$$

$$\epsilon_\phi = \frac{U}{r} \qquad (5)$$

Equations 1 to 5 are the basic expressions which are necessary and sufficient to completely solve the problems of the spherical shell subjected to internal pressure, external pressure or a combination of both. When the final expressions are expressed in general form it is only necessary to put in the proper boundary conditions to obtain the desired specific solutions for any condition of pressure loading.

Proceeding with the solution, we first differentiate equation 1 with respect to r and introduce equations 4 and 5 into the differential equation. This yields equation 6 as given below.

$$\frac{d\sigma_r}{dr} = (\lambda + 2G)\frac{d^2U}{dr^2} + 2\lambda\left[\frac{1}{r}\frac{dU}{dr} - \frac{U}{r^2}\right] \qquad (6)$$

Note: The notation T & G refers to "Theory of Elasticity" by Timoshenko and Goodier, Second Edition, 1951, McGraw-Hill Book Co.

The term $\frac{d\sigma_r}{dr}$ can be eliminated by the simple expedient of replacing it by its equal from equation 1. Now we introduce, for the resulting term $\sigma_\phi - \sigma_r$, the result of subtracting equation 2 from equation 3. This results in the following expressions:

$$\frac{2}{r}(\sigma_\phi - \sigma_r) = (\lambda + 2G)\frac{d^2U}{dr^2} + 2\lambda\left[\frac{1}{r}\frac{dU}{dr} - \frac{U}{r^2}\right] \quad (7)$$

$$\sigma_\phi - \sigma_r = \frac{4G}{r}(\epsilon_\phi - \epsilon_r) = \frac{4G}{r}\left[\frac{U}{r} - \frac{dU}{dr}\right] \quad (8)$$

$$\therefore (\lambda + 2G)\left[\frac{d^2U}{dr^2} + \frac{2}{r}\frac{dU}{dr} - \frac{2}{r^2}U\right] = O \quad (9)$$

Since it is physically impossible for the term $\lambda+2G$ in equation 9 to be zero, the remaining part of the product in this equation must be zero. If we multiply this non-zero part by r^2 the following homogeneous linear differential equation with varying coefficients is obtained:

$$r^2\frac{d^2U}{dr^2} + 2r\frac{dU}{dr} - 2U = O \quad (10)$$

This particular differential equation is of classic form and is known as the Euler equation[2]. The solution to this equation is obtained by substituting $r = e^t$, and this yields (after some manipulation) the following general solution:

$$U = Ar + Br^{-2} \quad (11)$$

So far nothing has been done to introduce the loading conditions, i.e., the pressure. It is at this point that the boundary conditions must be introduced to evaluate the constants in equation 11. This can be done by noting that under internal pressure only, the radial stress σ_r at the inner surface is just the pressure and at the outer surface is zero. These conditions can be expressed mathematically by utilizing equations 2, 4 and 5 and they then yield equations 12 and 13. By differentiating equation 11 the term $\frac{dU}{dr}$ is obtained

$$(\lambda + 2G)\frac{dU}{dr} + 2\lambda\frac{U}{r} = P_i, @\ r = r_i \quad (12)$$

$$(\lambda + 2G)\frac{dU}{dr} + 2\lambda\frac{U}{r} = O, @\ r = r_o \quad (13)$$

and the term $\frac{U}{r}$ is obtained directly from equation 11.

$$\frac{dU}{dr} = A - 2Br^{-3} \quad (14)$$

[2]T & G, Pages 65, 66.

$$\frac{U}{r} = A + Br^{-3} \qquad (15)$$

Substitution of expressions 14 and 15 into 12 and 13 yields two equations, namely 16 and 17 in the two unknowns A and B. Solving for these unknowns we obtain the following expressions:

$$A = \frac{P_i}{(3\lambda + 2G)[r_o^{-3} - r_i^{-3}]} \qquad (16)$$

$$B = \frac{P_i}{4G} \frac{1}{[r_o^{-3} - r_i^{-3}]} \qquad (17)$$

With these constants evaluated, it is now possible to write the desired solutions for the strain components and the displacement. This is done by inserting the values of A and B from equations 16 and 17 into equations 11, 14 and 15. This gives us equations 18, 19 and 20 below.

$$\boxed{\epsilon_r = \frac{P_i}{(3\lambda + 2G)[r_o^{-3} - r_i^{-3}]} - \frac{P_i}{2Gr^3[r_o^{-3} - r_i^{-3}]}} \qquad (18)$$

$$\boxed{\epsilon_\phi = \frac{P_i}{(3\lambda + 2G)[r_o^{-3} - r_i^{-3}]} + \frac{P_i}{4Gr^3[r_o^{-3} - r_i^{-3}]}} \qquad (19)$$

$$\boxed{U = \frac{P_i}{(3\lambda + 2G)r[r_o^{-3} - r_i^{-3}]} + \frac{P_i}{4Gr^3[r_o^{-3} - r_i^{-3}]}} \qquad (20)$$

The remaining task to complete the total solution is the determination of the stress components. The simplest method of doing this is to utilize equations 2 and 3 for the stress components in terms of the strain components. Rearranging equation 2 in more usable form yields:

$$\sigma_r = \epsilon_r(\lambda + 2G) + 2\lambda\epsilon_\phi \qquad (21)$$

Substitution from equations 18 and 19 into equation 21 gives the desired result for the radial stress component. However, this result can be simplified considerably by combining terms and reducing constants. Performing this simplification gives the final result for the radial stress component as equation 23.

$$\sigma_r = \left[\frac{P_i}{(3\lambda+2G)[r_o^{-3}-r_i^{-3}]} - \frac{P_i}{2Gr^3[r_o^{-3}-r_i^{-3}]}\right](\lambda+2G)$$

$$+2\lambda\left[\frac{P_i[r_o^{-3}-r_i^{-3}]^{-1}}{(3\lambda+2G)} + \frac{P_i[r_o^{-3}-r_i^{-3}]^{-1}}{4Gr^3}\right] \qquad (22)$$

$$\sigma r = P_i \frac{r_i^3}{r^3}\left[\frac{r^3 - r_o^3}{r_i^3 - r_o^3}\right] \quad (23)$$

Proceeding in a similar manner as above, we can establish the tangential stress component. The following steps are analogous to equations 21, 22 and 23:

$$\sigma_\phi = 2\epsilon_\phi[\lambda + G] + \lambda\epsilon_\gamma \quad (24)$$

$$\sigma_\phi = \left[\frac{P_i(2\lambda+2G)}{(3\lambda+2G)[r_o^{-3}-r_i^{-3}]} + \frac{P_i(2\lambda+2G)}{4Gr^3[r_o^{-3}-r_i^{-3}]}\right] + \left[\frac{P_i(\lambda)}{(3\lambda+2G)[r_o^{-3}-r_i^{-3}]} - \frac{P_i[\lambda]}{2Gr^3[r_o^{-3}-r_i^{-3}]}\right] \quad (25)$$

$$\sigma_\phi = -\frac{P_i}{2}\frac{r_i^3}{r^3}\left[\frac{r_o^3 + 2r^3}{r_o^3 - r^3}\right] \quad (26)$$

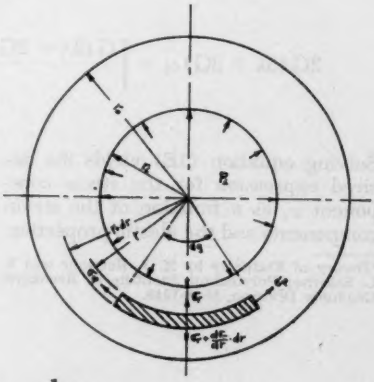
In order to check part of the work, we note that when $r = r_i$ σ_r from equation 23 is equal to P_i and when $r = r_o$ it equals zero. This corresponds exactly to the boundary conditions used to determine the constants A and B in equation 11. The final solutions given in equations 23 and 26 correspond to those in standard texts on elasticity.[1]

The specific problem dealt with in this paper has been the case of internal pressure. If the spherical container were subject to external pressure only the entire procedure outlined above will apply with only the appropriate change in boundary conditions in the general solution of equation 11. The resulting solution will of course hold only for the condition of external pressure. In order to establish the solution for the case of both internal and external pressure acting simultaneously it is only necessary to add the two solutions. In this case it is possible to superpose the separate solutions to obtain the combined condition.

Appendix A

The Equation of Equilibrium for a Sphere[1]

The general differential equation of equilibrium of a sphere (subjected to internal pressure or external pressure or both) can be readily arrived at by considering figure 1 below:
Consider the small element cut out of the sphere by the two concentric speri-. cal surfaces established by radii r and r+dr and the cone whose central angle is given by dq. The desired equilibrium equation is:



$$\sigma_r + \frac{d\sigma_r}{dr}.dr$$

[1] T & G, page 359.

$$\sigma_\phi \left[\frac{\pi r}{2}\right] dr\,(dq)^2 = \frac{d\sigma_r}{dr}\frac{\pi r^2}{4} dr\,(dq)^2 + \sigma_r \frac{\pi r}{2} dr\,(dq)^2 \qquad (A)$$

Note that dr and $(dq)^2$ are terms common to each factor of equation (A). With the above and reducing constants we arrive at equation (B) in the desired form:

$$\frac{d\sigma_r}{dr} + \frac{2}{r}(\sigma_r - \sigma_\phi) = O \qquad (B)$$

Appendix B

Lamé Inversion for Centric Symmetry

Hooke's law enables one to readily write the relations giving the components of strain as functions of the components of stress. Using the fact that stress and strain components can be superposed (as long as the relations between them are linear) we can write the generalized form of Hooke's law for the case of centric symmetry:

$$E\epsilon_r = \sigma_r - 2v\sigma_\phi \qquad (1A)$$

$$E\epsilon_\phi = \sigma_\phi - v(\sigma_r + \sigma_\phi) \qquad (1B)$$

We may now place Lamé constants in terms of the Hooke moduli and obtain the following expressions:[1]

$$E = \frac{G(3\lambda + 2G)}{\lambda + G} \quad ;$$

$$v = \frac{\lambda}{2(\lambda + G)} \qquad (1C)$$

Placing expressions (1C) into equation (1A) we can solve for σ_ϕ and obtain equation (1D):

Now the substitution of these equations, namely (1D) and (1C), into equation (1B) yields (1E):

$$\sigma_\phi = \frac{-G(3\lambda + 2G)\epsilon_r + (\lambda + G)\sigma_r}{\lambda} \qquad (1D)$$

$$2G(3\lambda + 2G)\epsilon_\phi = \left[\frac{G(3\lambda + 2G)\epsilon_r - (\lambda + G)\sigma_r}{\lambda}\right](\lambda + G) - \lambda\sigma_r \qquad (1E)$$

Solving equation (1E) yields the desired expression for the stress component σ_r as a function of the strain components and the elastic properties:

$$\sigma_r = \lambda[2\epsilon_\phi + \epsilon_r] + 2G\epsilon_r \qquad (1F)$$

In a similar manner we derive the expressions for σ_ϕ:

$$\sigma_\phi = \lambda[2\epsilon_\phi + \epsilon_r] + 2G\epsilon_\phi \qquad (1G)$$

[1]Theory of Elasticity by H. J. Reissner and V. L. Salerno; Polytechnic Institute of Brooklyn, Graduate Division, 1948-1949.

Nomenclature

E=Modulus of Elasticity.
G=Modulus of Elasticity in shear.
ν=Poisson's Ratio.
λ=Lame's Constant.
ϵ_r=Radial strain component.
ϵ_ϕ=Tangential strain component.
σ_r=Radial normal stress component.
σ_ϕ=Tangential normal stress component.
r=Radius.
r_o=Outside radius.
r_i=Inside radius.
P_i=Internal pressure.
U=Total displacement radially.
e=Base of natural logarithms.
t=Variable (used to transform differential equation).
A=Constant.
B=Constant.
q=Angle.

References

1. "Theory of Elasticity" by Timoshenko and Goodier, Second Edition, 1951, McGraw-Hill Book Co.
2. "Theory of Elasticity" by A. E. H. Love, Cambridge, 1927.
3. "Differential Equations" by L. R. Ford, First Edition, 1933, McGraw-Hill Book Co.

THE NEW METAL TITANUIM

ACKNOWLEDGEMENT

This paper, published in the November 1953 issue of "The Journal of the Institute of Metals," was read at the annual Autumn Meeting of The Institute of Metals in Southport, on 21 September 1953. It was written by Maurice Cook, Joint Managing Director, Imperial Chemical Industries, Ltd., Metals Division. A condensed version of the same paper was published in the February 1954 issue of the JOURNAL.

I.—HISTORY

It may seem somewhat odd to refer to titanium as a new metal when, in fact, its existence was known more than 150 years ago. Since that time it has, of course, been familiar to chemists as a metallic element with a recognized place in the Periodic Table, many of its compounds have long been used in quantity commercially, and for some years metallurgists have made use of it as a minor but not unimportant constituent in the production of both ferrous and non-ferrous alloys. It is, however, only within the last five years or so that the metal has been produced on a tonnage basis by industrially worked processes. Until a few years ago few people had even seen it, it is not yet a common metallurgical commodity, and few metallurgists have experience of it or know much about it. This, therefore, is the justification for referring to it is as a new metal, which it is, in as much as we are just now witnessing its industrial birth.

In 1790, a Cornish clergyman named Gregor recognized that titanium dioxide was the oxide of a hitherto unknown metal, and in 1795 the Austrian chemist Klaproth came to the same conclusion, and although he did not isolate the metal, he called it titanium. It was, however, the famous Swedish chemist Berzelius who first produced titanium, albeit in a very impure state, in 1825, the same year as that in which the Danish chemist Oersted is credited with having first isolated aluminum. Metal of about 95% purity was produced in 1887 by Nilson and Pettersson by reducing titanium tetrachloride with sodium, and in 1895 Moissan, by reduction in an electric arc, made metal of 98% purity, but it was brittle, and although in 1910 Hunter, in the U.S.A., made titanium of about 99.5% purity, which was ductile when hot, it was brittle in the cold state. It was in 1925 that van Arkel and de Boer produced experimentally, by the dissociation of the

tetraiodide, metal sufficiently pure to establish the fact that titanium was ductile when cold. This indeed was the outstanding discovery made about titanium since its isolation in a crude form a hundred years earlier, and the discovery which indicated its potentialities. The assessment of the characteristics of titanium that could be made, following its experimental production in a pure form, provided a far different picture of the metal and its industrial future than it had previously been possible to visualize. The technique used by van Arkel and de Boer was one which on the grounds of cost and technological difficulties could not readily be translated into an industrial process, but their achievement provided the spur for other work on methods of producing titanium which might constitute the basis of industrial processes for its manufacture in quantity and at much lower cost.

In 1940, Kroll described a route for the production of titanium which, with some modifications, is the method by which most of the current output is produced, and it was, in fact, the first process which provided the prospect of manufacturing ductile titanium on an industrial scale. I will refer to it in a little more detail later, but essentially it consisted of reducing titanium tetrachloride with metallic magnesium. This pioneer work was followed up in the United States by research teams of the Bureau of Mines, who were responsible for an immense amount of valuable work which was the prelude to the first commercial production of the metal in the U.S.A. in 1948, in which year about 30 tons were made. This figure was almost doubled two years later, and in 1952 it is reported to have been about 1000 tons. Various figures have appeared for the estimated U.S. production for this year, and they range up to about 10,000 tons, but much lower figures have been more recently quoted for what the actual production is likely to be. It has been suggested that outputs of the order of 20,000 tons per annum may be reached within the next two or three years in the U.S.A., to which country most of the titanium production has hitherto been confined. In Great Britain commercial production so far has been on a very limited scale, but within the next two or three years it may well reach a figure approaching 2000 tons, and interest is also being shown in its manufacture in other countries. That broadly and briefly is the history of the metal to date.

II.—GENERAL

During the past six or seven years or so, an enormous amount of scientific and technological work has been carried out on titanium, mostly in the U.S.A., but not only there. On work of this kind many millions of pounds have been spent, and not only is the effort still proceeding, but it is being intensified. Never before has there been in so short a time so much research activity directed to a single industrial metal.

Clearly there must be a reason and a justification for this, and indeed there is. Briefly, it is that the metal has attractive physical and mechanical properties, a high strength: weight ratio, and outstandingly good resistance to corrosion generally. Its importance as a very desirable if not uniquely suitable material for several aircraft components was recognized as soon as sufficient of it had been made to enable its properties to be determined, if only approximately, and for evaluation tests to be made. Much of this work was done on metal com-

pacted from powder before techniques for melting in quantity were devised and developed. Limited though they were at the time, the results were enough to open up to the imagination a vista of possibilities extending far beyond such immediate and current uses as the properties of the metal and some of its alloys justify even at present prices. The early results and the picture of future possibilities which they unfolded, stimulated the vast volume of work which has since gone on concerning methods of production and fabrication of titanium and its alloys.

Although the future is unpredictable, the possible position of titanium in relation to other metals is a matter of no small interest to both metal producers and consumers alike. Of all the known chemical elements more than seventy are classified as metals. About half of these are so rare and comparatively unknown that no appreciable use is made of them. Many of the remainder have significant and indeed important uses for specialized applications, even though in small quantity, whilst a number are used quite widely for many purposes in fairly large quantities. The remarkable advances in transport, communications, and various other branches of engineering activity in the last decade or two have necessitated the use of such a wide variety of metals and new alloys—one of the most notable features in the metallurgy of our time—that we can regard ourselves as living in an age of new metals.

But of all these there are only eight which are normally regarded as basic in the sense that they form what might be called massive metallurgical industries, in which primary metal production has reached annual figures of 100,000 tons or more, and so far as five of them are concerned, individual outputs extend to millions of tons. These eight metals are all well known to you for they are iron, copper, zinc, aluminum, lead, tin, nickel, and magnesium, and some of them have served the needs of mankind through centuries of time. The consumption of metals both new and old is proceeding at a greater rate than ever, and it has, in fact, been reported, for example, that in the U.S.A. alone since the First World War most metals have been used in quantities exceeding the total world consumption for all time up to 1914.

Although its current production runs to an annual level of a few thousand tons, the use of titanium, because of its price, is limited at present to special purposes. This indeed may long continue to be the position. On the other hand, if more convenient and cheaper methods of extraction were devised, so enabling its cost to be very substantially reduced, then it might well become a large-tonnage basic metal. In these days of high metal consumption which have witnessed temporary shortages, unbalances, and high costs amongst some of the older strategic materials, as well as uncertainties regarding the future availability of some of them, the advent of a new metal is a matter of no little interest and moment. Especially is this so when it is known that the metal and its alloys possess properties which make them not only attractive for special uses, but suitable also for ordinary and more general applications involving large tonnage consumption.

It is, however, a far cry from the present position of expensive production and processing to what still is the purely imaginative one of manufacture at price levels even approaching those of the more costly basic metals. All the major problems connected with the extraction, melting, fabrication of titanium, and there are indeed many, stem from its very high degree of reactivity when hot and particularly

when it is molten. Its great affinity for oxygen, the extremely low free energy of its lower oxides, the solubility of oxygen, and the marked embrittling effect which quite small traces of it have on the metal, have proved major obstacles in the production of titanium of satisfactory quality by direct reduction of its oxide, and in the reduction processes so far developed and worked industrially it has been found necessary to start with oxygen-free compounds. Since the molten metal attacks all the known refractory materials used for lining metal-melting furnaces and for making crucibles, because of the solubility of nitrogen and oxygen in titanium, and to a lesser extent because of its high melting point, which is at present accepted as 1725° C., special equipment and procedures involving melting *in vacuo* or in argon, far more costly to operate than the techniques usually employed for melting other metals, have had to be developed. I will refer later in a little more detail to reduction and melting operations, but what I have already said will make it clear enough that many serious problems will have to be solved before titanium can become a readily available metal. Formidable as many of these are, there is justification for a reasonable measure of optimism. Notwithstanding the difficult and complicated nature of the most important extraction process so far developed and which was first used on an industrial scale so very few years ago, the amount of progress both in metal production and in improvements to the process itself are quite impressive. It may well be that eventually other routes, more attractive either economically or technically, or both, will be devised. Although this is not the occasion for speculating in detail on future price trends of titanium, it is clear that success in any such developments as the scaling up and substantial improvement of existing production methods, or the devising of superior new ones, would undoubtedly result in price reductions and conceivably, in due time, bring titanium into the range of basic metals which its general properties and its abundant and wide distribution over the world in the form of workable ores would make possible.

III.—OCCURRENCE

In Fig. 1 is shown the relative abundance of some of the important metallic elements in the lithosphere, from which it can be seen that of the so-called common or basic metals, that is, those which are or can be used in quantity for a wide range of ordinary purposes and form the basis of major alloy groups, only aluminum, iron, and magnesium are more plentiful than titanium. The extent of its occurrence is many times greater than that of several well-known metals, such as copper, zinc, lead, and tin, put together, the extensive use of which, in addition to the obvious one of suitability, is also associated with the fact that their ores are fairly readily obtainable or accessible and yield up their metal content relatively easily. Titanium

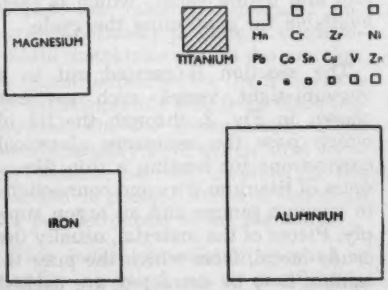


FIG. 1.—Relative Abundance of Structural Metals.

ores, on the other hand, whilst plentiful and accessible enough, are most discouragingly resistant to reduction.

In view of the present great interest in the metal and its potential importance, the sources from which it is obtained justify some mention. The chief ores of titanium are ilmenite ($FeTiO_3$), a combination of iron and titanium oxides, and the oxide rutile, both of which derive originally, as decomposition products, from granites and pegmatites. Titanium ores have long been used as a source of titanium dioxide for the paint and other industries, the world production of ilmenite concentrates amounting in 1951 to no less than 1,183,000 tons. This mineral occurs as massive deposits in Canada, U.S.A., Norway, and Russia, and as beach sands in Queensland, Travancore, and Florida. Rutile, which occurs to a much lesser extent, is found principally in Australia and the U.S.A. From information already known about deposits, it is evident that abundant supplies of ore exist. For example, one deposit in Eastern Quebec alone is estimated to contain the equivalent of about 25 million tons of titanium metal, but in addition to rich ores, there are vast quantities of lower-grade ores in every part of the world. In short, and as far as the future can be foreseen, there are supplies of titanium ores to meet production levels comparable with those of today's basic metals.

IV.—REDUCTION PROCESSES

1. THE VAN ARKEL PROCESS

In turning now to a brief survey of some of the techniques by which metallic titanium is produced, the iodide method of van Arkel and de Boer merits a description, however brief, since it was by its use, although as a laboratory experiment, that the first ductile titanium was made and because it is still the method employed for producing the metal in its purest form. In principle, it is an elegant process and in theory quite simple, for its operation turns on the fact that at relatively low temperatures titanium reacts with iodine to form titanium tetraiodide, which at higher temperatures dissociates into metallic titanium and iodine vapor, which is then available for continuing the cycle.

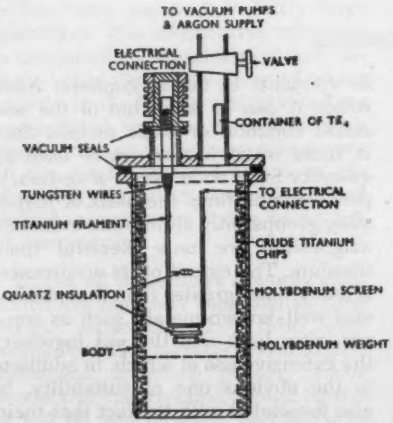


FIG. 2.—Plant for Production of Titanium by Thermal Decomposition of Titanium Tetraiodide.

The reaction is carried out in a vacuum-tight vessel such as that shown in Fig. 2, through the lid of which pass the necessary electrical connections for heating a thin filament of titanium wire and connections to vacuum pumps and an argon supply. Pieces of the material, usually the crude metal, from which the pure titanium is to be extracted, are packed into the annular space between the wall of the chamber and an inner re-

fractory-metal radiation screen, usually made of perforated molybdenum sheet. The lid with its attachments is then fitted to the vessel which is heated to about 600° C., kept under vacuum until all gases are removed, and the temperature then reduced to about 200° C., when the iodine or titanium tetraiodide is released from a capsule and commences to react with the crude titanium. By the passage of an electric current, the filament of fine pure titanium wire, disposed as will be seen in the form of what has fancifully become known as a "hairpin," is heated to 1400° C. On to this, under these conditions, titanium from the tetraiodide is deposited, the liberated iodine diffuses back through the perforated screen to combine with more titanium, and so the process continues. It ceases when the filament has grown to such dimensions that either the electrical seals cannot carry the increased current required to maintain the filament at the temperature of decomposition, or the total amount of heat liberated in the container becomes too great to be effectively dissipated, and, in consequence, overheats the interior of the reaction vessel. When the operation is finished, cooling is effected as quickly as possible, argon gas being simultaneously admitted, until normal temperature is reached.

Since neither oxygen, nitrogen, or carbon, nor other non-metallic impurities normally present in crude titanium metal take part in the reaction, the metal deposited on the filament is almost completely free from these impurities. On the other hand, some metals, notably iron, which form volatile iodides, become involved in the reaction if present and are found in the purified metal of the filament.

This iodide-dissociation method is usually operated as a purification process, but it clearly has possibilities for primary-metal production,

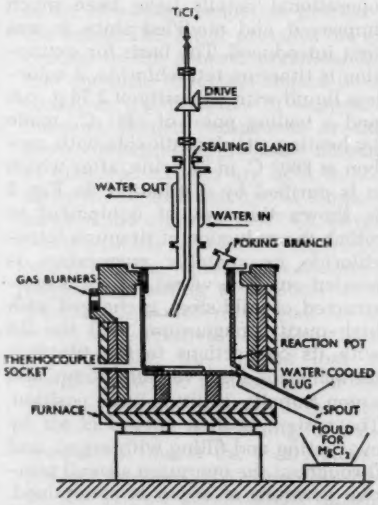


FIG. 3.—Plant for Magnesium-Reduction Process.

and some consideration has naturally been given to these, although no major new developments have been reported. It would, for example, be possible to extract the metal content in this way from titanium carbonitride, which is made by heating ilmenite with carbon in an electric furnace. In its present form, the thermal-dissociation process has several limitations including those of slowness and the use of expensive iodine, small losses of which on large-scale working would materially affect costs. It would, however, be possible, for example, to have alternatives to a heated filament for effecting dissociation and, moreover, on such heated surfaces other compounds could possibly be used as the source of metal.

2. THE KROLL PROCESS

The process by which practically all of the titanium now being made industrially is produced is that developed by Kroll, although the plant and

operational details have been much improved and modified since it was first introduced. The basis for extraction is titanium tetrachloride, a colorless liquid with a density of 1.76 g./c.c. and a boiling point of 136° C., made by heating titanium dioxide with carbon at 800° C. in chlorine, after which it is purified by distillation. In Fig. 3 is shown the type of equipment in which the reduction of titanium tetrachloride by metallic magnesium is carried out. The vessel, which is constructed of mild steel, is charged with high-purity magnesium, and the lid with its connections to the titanium tetrachloride feed, vacuum pump, and argon supply, is fitted into position. The system is then purged of air by evacuating and filling with argon, and throughout the operation a small positive pressure of argon is maintained. The whole is then externally heated to the melting point of magnesium, when titanium tetrachloride is slowly introduced through the rotary feed pipe. This pipe, which passes through a sealing gland, is bent at the delivery end, and it is rotated during the reaction to ensure even distribution of the tetrachloride. The reaction is strongly exothermic, and as there is a risk of iron contamination from the containing vessel at temperatures of the order of 900° C., the temperature is carefully controlled and only permitted to rise to about 800° C., at which it is maintained by regulating the supply of tetrachloride and the external heating. Molten magnesium chloride which is formed collects at the bottom of the reactor and is tapped off during the operation. On completion of the run, the reactor, still under a positive pressure of argon, is allowed to cool to room temperature, after which the lid is removed and the vessel transferred to the purification unit.

It contains a mass of titanium mixed with magnesium chloride and magnesium, and in the early days of the process this was chipped out and extracted with dilute hydrochloric acid, washed, and dried. The coarse titanium powder so produced contained considerable quantities of both hydrogen and oxygen. The former could be, and was, removed by heating *in vacuo* at 800°-900° C., but the oxygen remained making the metal hard, brittle, and consequently difficult to fabricate. As a method of separation from reaction products and purification, leaching has given place to the more effective treatment at high temperature under high vacuum, a process previously developed in the manufacture of zirconium. In this, as shown in Fig. 4, the

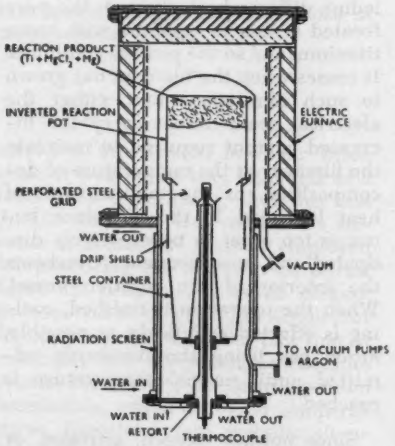


FIG. 4.—Plant for Vacuum Purification of Product of Magnesium-Reduction Process.

steel reactor containing its charge of intermixed sponge metal is introduced in an inverted position into a vertical retort which can be made gas-tight and connected either to vacuum pumps or an argon supply. The upper portion of the retort is surrounded by a removable electric furnace and the lower part by a water-cooled jacket. Mounted within the retort is a steel

container for collecting the magnesium chloride, which is driven off from the sintered mass in the reaction pot and falls through a perforated grid, the magnesium being volatilized and condensing on the radiation screen. The operation is carried out under high vacuum, the pressure inside the retort being reduced initially to 1 micron and held at a low value thereafter. After removal of the gas, the temperature of the retort is raised to about 800° C., maintained there for several hours, and then allowed to cool, argon being admitted during the final stages of cooling. At the finish there is left in the reactor only metallic titanium, a coke-like mass to look at, which is then broken up and ground to a suitable size for melting.

Involving as it does initially expensive materials, that is, pure titanium tetrachloride, magnesium metal of high purity, argon gas, and difficult operational techniques, the process is inevitably an expensive one. Nevertheless, it is workable industrially, and it has been the means of providing, even if so far in relatively small quantity at comparatively high cost, metal that has been wanted. Among the further improvements to the method that are envisaged is the removal of some of its limitations as a batch process by transforming it into a continuous operation.

3. POSSIBLE ALTERNATIVE REDUCTION METHODS

Because of the obvious desirability of producing titanium more cheaply, great interest centers around other methods of extraction, and a good deal of work is going on with this object. For example, further consideration has been given to the method of reducing the tetrachloride with sodium which, as already noted, was first done experimentally several years ago, and another method that has been worked is the two-stage reduction process of the oxide. This latter provides the exception to the general understanding that chemical reduction cannot be effected in the presence of oxygen. If titanium-oxygen compounds or titanium containing appreciable amounts of dissolved oxygen are held in contact with metallic calcium at temperatures of the order of 1000° C., oxygen reacts with the calcium to form calcium oxide, and the equilibrium amount of oxygen remaining in solution in the titanium is sufficiently small for the metal to be relatively soft and ductile. Theoretically, this means that the whole reduction process can be carried out without recourse to the intermediate stage of forming a halide compound, one of the costly steps in present methods. It has not, however, so far proved economically possible to effect the whole of the reduction by calcium alone, but by reacting the oxide with magnesium a lower oxide of titanium is produced. When the product of this reaction is leached to remove magnesium and magnesium oxide, the purified lower oxide of titanium remains. This is reduced by calcium and the residual calcium oxide removed by a second leaching. Metallic titanium is thus produced, but the oxygen content of metal hitherto so made on an industrial scale appears to have been too high for it to be suitable for ordinary fabrication processes.

Titanium powder can also be made by processes involving the preparation and subsequent decomposition of the hydride, but such routes so far have not resulted in the production of pure metal at reduced cost.

Where chemical methods are outstandingly difficult or otherwise unattractive, attention naturally directs itself to processes of electrolysis on which, for the extraction of titanium, large sums of money have been spent, but up to the present no industrial

process of this kind has been developed. The same restriction which the ruinous solubility of oxygen in metallic titanium imposes on materials for reduction by chemical processes, would seem to render unlikely the successful electrolysis of aqueous solutions, as can be done for copper, or the use of oxides dissolved in molten salts, as, for instance, in the extraction of aluminum. Furthermore, no suitable oxygen-free non-aqueous organic solvents have been disclosed, and titanium tetrachloride itself is a very poor conductor of electricity.

Experimentally, titanium has been produced in small quantities by electrolysis of titanium trichloride and other lower halides dissolved in fused lithium and potassium chlorides and similar electrolytes, but as the deposit is in the form of flakes or dendrites, the problem still remains of the satisfactory separation of the metal from the electrolyte. This has, in fact, proved a serious limitation in the electrolytic process as applied to high-melting-point metals with high affinity for oxygen, since it has not been possible to produce metal in massive form from fused-salt electrolytes unless the metals are molten at the temperature of electrolysis as, for instance, sodium, magnesium, and aluminum, and even the higher-melting-point metals such as calcium and Mischmetall. Modifications of the electrolytic process in which the metal is dissolved in another low-melting-point metal which acts as a liquid cathode is possible, as, for example, in cells using mercury or molten zinc, but these again would involve a subsequent distillation process for the separation of the solvent metal comparable with the Kroll vacuum-purification method.

The lower chlorides of titanium undergo disproportionating reactions resulting in the formation of titanium tetrachloride and titanium metal as follows:

$$2TiCl_3 = TiCl_4 + TiCl_2$$
$$2TiCl_2 = TiCl_4 + Ti$$

Titanium trichloride, which is formed when excess titanium tetrachloride is allowed to react with magnesium, consists of violet-colored crystals, and is always accompanied by the black, unstable dichloride produced by the first reaction just referred to. Titanium trichloride can also be formed by the direct reduction of the tetrachloride by hydrogen, forming HCl as a co-product. Some attempts have been made to produce titanium metal by this disproportionation reaction, but little success has yet been achieved. At present, the conditions under which these reactions occur are not sufficiently understood to indicate how much promise they hold as the basis of a workable process.

Because of the very low free energy of its oxides, titanium metal in the presence of water vapor reacts at elevated temperatures almost irreversibly to form oxide and hydrogen. It is, however, theoretically possible at extremely high temperatures for this reaction to be reversed. A very large excess of hydrogen would be required to remove the water vapor and prevent recombination with the titanium and for the same reason the reaction would have to be carried out at fairly low pressures. Moreover, the necessity for operating at very high temperatures would require the solution of metallurgical engineering problems of a major character.

These are but a few examples of the many possible approaches that are being considered, and, in some instances, actually investigated, as alternative routes on which industrial processes for the production of titanium might be based.

V.—MELTING

The great affinity of titanium for oxygen and nitrogen, which necessitates the carrying out of extraction processes in the complete absence of air, also demands the same conditions for melting. Metal produced by thermal decomposition on a heated filament can be worked directly into small-diameter rod or wire, but the product of the chemical reduction processes now being used needs to be consolidated for further fabrication. In the pioneer days, this was done by compacting titanium powder, but the limitations of that technique for the production of the metal and its alloys in quantity in wrought forms made the development of melting techniques imperative. Since, as already mentioned, titanium attacks all the refractory materials normally associated with metal melting, methods not involving their use had to be devised or adapted.

The one partly exceptional refractory material is carbon, and methods of melting *in vacuo* or in an atmosphere of argon in graphite crucibles heated by high-frequency induction or graphite resistors were developed and used. When molten, however, titanium dissolves carbon, and although in small quantities the presence of this element is not seriously detrimental, the extent of carbon contamination when melting in graphite is considerable and uncertain.

The technique now generally employed is based on the discovery of von Bolton in 1905 that high-melting-point metals—his experiments were conducted on tantalum—can be melted in a water-cooled copper receptacle by striking an arc between an electrode and the metal to be melted. Thus the particular feature of this method is that the problem of finding a stable refractory material is avoided, rather than solved, by melting titanium in a vessel which can conveniently and effectively be kept cold

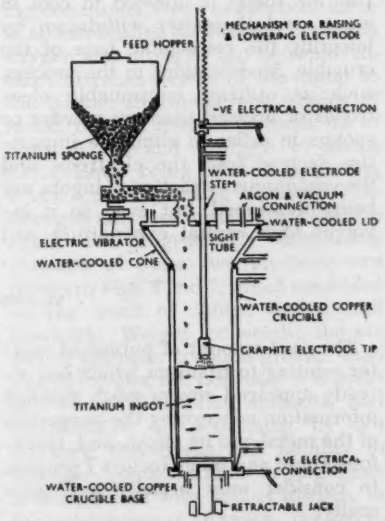


FIG. 5.—Titanium Arc-Melting Unit.

enough to prevent any bonding or interaction between the two.

It has been developed in a comparatively short time from laboratory-scale equipment to units capable of producing ingots weighing up to 4000 lbs. This type of melting plant is illustrated in Fig. 5. It consists of water-cooled copper crucible fitted with a water-cooled electrode having either a tungsten or a graphite tip, a hopper for feeding in crushed vacuum-purified titanium sponge together with any alloying ingredients that may be required, a sight tube, and connections to vacuum pumps and argon and water supplies. In operation a quantity of sponge is placed in the crucible, which is then evacuated and filled with argon. The arc is then struck between the electrode and the charge, and as the latter melts more metal is fed in from the hopper and the electrode progressively raised. In this way the ingot is built up, although at any moment the pool of metal in the molten

state is quite small. At the end of the run the metal is allowed to cool in argon, and thereafter withdrawn by lowering the retractable base of the crucible. Modifications to the process, such as utilizing consumable electrodes of pressed titanium powder or sponge in order to eliminate impurities derived from the electrode, and the continuous retraction of ingots, are being developed, but even so it involves high capital expenditure and working costs, and to obtain uniformity of composition under such conditions of melting requires careful operational control. Although, as already noted, relatively large ingots are being made as the basis for the production of titanum and its alloys in wrought forms, nevertheless, the problem of devising cheaper and better melting techniques is second only in importance to developing cheaper and improved extraction processes.

VI.—PROPERTIES

The vast amount of published matter relating to titanium which has already appeared covers much detailed information concerning the properties of the metal and its alloys, and, therefore, these and other factors I propose to consider only broadly and generally.

Titanium undergoes an allotropic transformation at 882° C., above which temperature it has a body-centred cubic structure, known as the β phase, and below this temperature it has an hexagonal close-packed structure, known as the α phase. Pure titanium, such as that produced by the dissociation of titanium tetraiodide, is a relatively soft metal with high ductility. The α phase has a c/a ratio of 1.587, a value which is significantly lower than the theoretical value of 1.633 corresponding to ideal close packing. In this regard it differs from other hexagonal close-packed metals, such as magnesium, zinc, and cadmium, the c/a ratios of which are 1.624, 1.86, and 1.89 respectively, and in these metals the dominant deformation mechanism is slip on the basal planes. A low c/a ratio implies that prismatic and pyramidal planes are, relative to the basal plane, more closely packed, and consequently in titanium the former are slip planes.

High-purity titanium can be easily cold worked, and it can sustain deformation to the extent of reductions in area of more than 95% before annealing becomes necessary for further working. Its ultimate tensile strength is, however, only of the order of 15 tons/in.^{2}, with an elongation value on 2 in. of between 40 and 60%, and, therefore, as an engineering material or as a construction metal in a wider and more general sense, its possibilities are not comparable with those of commercial grades of titanium or of titanium alloys.

Commercially pure titanium as produced by chemical reduction methods, as, for example, the Kroll process, has considerably greater strength and lower ductility than iodide titanium, although the crystallographic features of the deformation mechanism are maintained. Ultimate tensile strength values of about 35-40 tons/in.^{2}, with 30-25% elongation, are typical of this quality of metal. The marked difference between these properties and those of the iodide metal is attributable to the presence of impurities, some of which in titanium have effects of unusual magnitude. Indeed, the technology of titanium is dominated by four impurities—oxygen, nitrogen, hydrogen, and carbon—all of which form interstitial solid solutions up to the limits of their solid solubilities,

which for the first three are about 30, 15, and 30 at.-%, respectively, while that of carbon is very limited. They find their way into the metal at various stages of processing and, in fact, most of the major problems arising in the production, melting, and subsequent working of the metal are associated with the necessity for excluding, or at least minimizing as far as possible, contamination by these impurities.

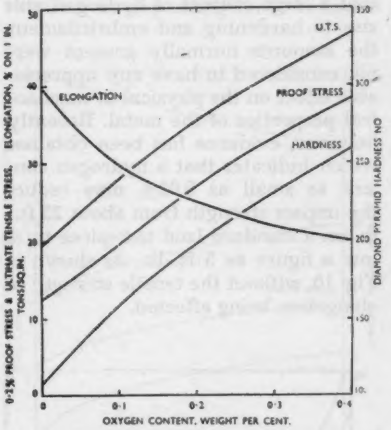


FIG. 6.—Effect of Oxygen Content on Mechanical Properties of Titanium.

So far as production technology is concerned, oxygen is, so to speak, in the light of present knowledge, titanium enemy number one, with nitrogen quite well behind in second place. Although their effects on processing and properties are pronounced, hydrogen and carbon are less significant impurities, since the former can be removed from the metal without recourse to remelting by heating to 800°-1000° C. *in vacuo*, while contamination by the latter can be limited to tolerable proportions by effective control of the purity of raw materials and melting conditions. Once in solution, there is no established method yet by which oxygen and nitrogen can be removed, short of reconversion of the metal to the halide. In commercial grades of metal, oxygen may be present up to about 0.25% and nitrogen to about 0.1%. Both bring about hardening with corresponding increase in strength and loss of ductility, and the effect of progressively increasing amounts of these two elements are shown in Figs. 6 and 7, which are based on the work of Jaffee, Ogden, and Maykuth. Weight for weight, the effect of nitrogen is much greater than that of oxygen, but normally it is present in much smaller amounts, and furthermore, in processing by hot working, the extent and liability to nitrogen contamination is negligible in comparison with that of oxygen. In the production of titanium, the overriding factor affecting the hardness of the metal is generally its oxygen content.

On heating in air at comparatively low temperatures, oxides and nitrides are formed on the surface of titanium, and at higher temperatures these diffuse into the metal. In the early days of titanium metallurgy it was thought necessary to carry out hot-working operations in the absence of air to avoid embrittlement, and to this end elaborate techniques were devised which involved enclosing the metal in gas-tight welded sheaths of steel. However, further experience in hot working and the more precise information which has been obtained on the rates of diffusion of these gases and their dependence on temperature, which has been shown to be approximately exponential, has indicated that titanium can be processed without an intolerable degree of oxygen contamination at temperatures in the range of about 850°-1000° C., according to circumstances and with certain

reservations. While this is generally true, the fact remains that some oxygen is taken up, and to that extent the metal is deteriorated. Hence the compelling need for precise control of hot-working and annealing operations to ensure the least possible contamination by oxygen because of its adverse effect both in further cold working and on the properties of the final product. The curves in Fig. 8 show the increase

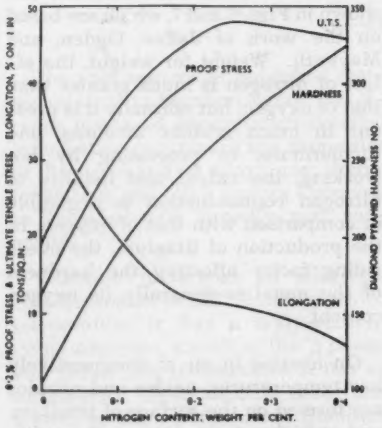


FIG. 7.—Effect of Nitrogen Content on Mechanical Properties of Titanium.

in hardness at and below the surface due to oxygen pick-up as a result of heating the metal for 1 hour at various temperatures.

The maximum solubility of carbon in α-titanium is about 0.2%, and it is less in the β phase, any present in excess assuming the form of discreet particles of titanium carbide. In amounts up to about 0.5%, the effects of carbon are not pronounced, except in so far as both machining and the production of ductile welds are more difficult. Metal containing up to this limiting quantity of carbon can be quite readily fabricated in the hot and cold states, but with greater amounts the hot-working properties seriously deteriorate. As will be seen from Fig. 9, which is based on the work of Finlay and Snyder, carbon, like oxygen and nitrogen, but to a markedly less degree, increases the strength and reduces the ductility of titanium.

Although it has been known since the early days of titanium production that a large content of hydrogen give rise to hardening and embrittlement, the amounts normally present were not considered to have any appreciable effect on the physical or mechanical properties of the metal. Recently, however, evidence has been obtained which indicates that a hydrogen content as small as 0.02% may reduce the impact strength from about 25 ft.-lb. on a standard Izod test-piece to as low a figure as 5 ft.-lb., as shown in Fig. 10, without the tensile strength or elongation being affected.

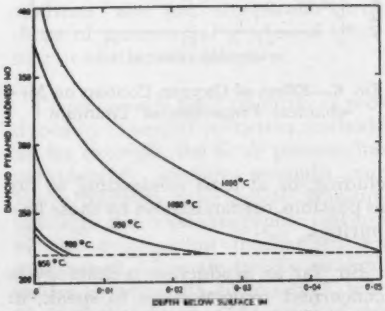


FIG. 8.—Hardness Gradient in Titanium on Heating for 1 Hr. in Air.

Commercially pure titanium can be readily hot worked by forging, rolling, extrusion, and other conventional methods, but in general, it is more resistant to cold working than are most non-ferrous alloys usually produced in wrought forms. One feature of titanium which adds seriously to

the difficulty of such cold-working operations as drawing of various kinds and deep pressing, is its unfortunate tendency to seize on other metals during sliding contact with them under pressure. So far no lubricant has been found which will prevent seizure of metal-to-metal surfaces, but this can be overcome to some extent through avoiding metal-to-metal contact by oxidizing the surface of the titanium or depositing on to it layers

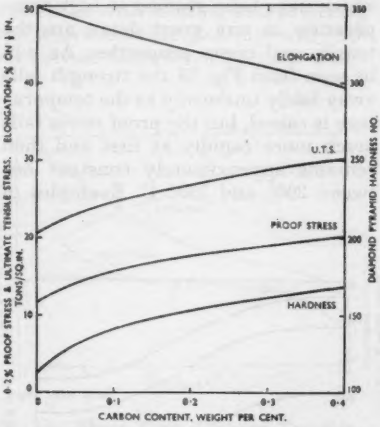


FIG. 9.—Effect of Carbon Content on Mechanical Properties of Titanium.

of other substances to serve as vehicles for the lubricant. Even under these conditions, only highly viscous or semi-solid lubricants can be used with any measure of success. Thus, for example, in drawing wire or tubes the metal surface can be oxidized and then carefully coated with molybdenum disulphide or a mixture of soap and calcium stearate. Alternatively, where circumstances necessitate it, recourse can be made to the technique of sheathing with another metal, which is removed by pickling towards the end of the cold-working operations.

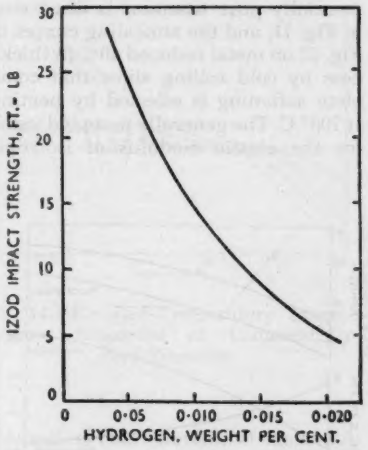


FIG. 10.—Relationship Between Impact Strength and Hydrogen Content of Commercially Pure Titanium.

In addition to the need for minimizing contamination in processing and for special techniques for drawing, such as those just referred to, another factor which looms large, if indeed not largest, in the economics of current wrought-titanium production, is that scrap metal cannot be remelted and returned to the production cycle. This arises partly from the fact that massive scrap cannot be fed into arc furnaces of the type at present employed for melting titanium, and partly from the necessity of avoiding cumulative contamination which would result from repeated melting and fabrication. Considerable effort is therefore being directed toward developing furnaces capable of melting scrap in the charge and in devising processes for the removal of at least some of the contamination before remelting.

The effect of cold working on some of the mechanical properties of com-

mercially pure titanium is illustrated in Fig. 11, and the annealing curves in Fig. 12 on metal reduced 40% in thickness by cold rolling show that complete softening is effected by heating at 700° C. The generally accepted value for the elastic modulus of isotropic

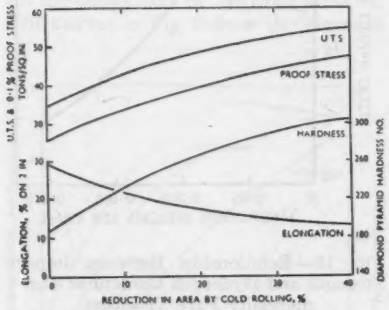


FIG. 11.—Effect of Cold Working on Commercially Pure Titanium.

material is 15×10^6 lb./in.^{2}, but like many other metals, titanium develops pronounced directional properties as a result of plastic deformation and, according to the crystal orientation in relation to the direction of testing, modulus values may vary between 14 and 20×10^6 lb./in.^{2}.

The fatigue properties of titanium are unlike those of most non-ferous metals for the S/N curve shows an approach to a true fatigue limit. The ratio of fatigue to tensile strength is generally greater than 0.5, but the most notable feature in which titanium excels other non-ferrous and ferrous alloys in respect of fatigue-resistance is the degree to which this ratio is maintained under corrosive conditions.

The impact strength of commercially pure titinium is of the order of 20-25 ft.-lb., and whilst, as already noted, this property is very susceptible to the presence of impurities, notably hydrogen, very much higher values characterize the pure metal.

Even at room temperature the creep properties are disappointing, and tests which have been carried out so far indicate that creep occurs when the metal is stressed near to its proof stress, which is unusual in a metal having so high a melting point.

The only mechanical properties which have been studied at high temperature in any great detail are the tensile and creep properties. As will be seen from Fig. 13 the strength falls away fairly uniformly as the temperature is raised, but the proof stress falls much more rapidly at first and then remains approximately constant between 200° and 350° C. Examples of

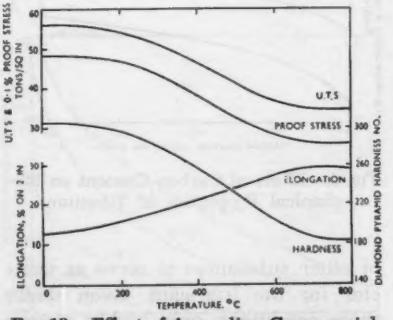


FIG. 12.—Effect of Annealing Commercially Pure Titanium 40% Cold Rolled (1 hr. soak at temperature.)

stress-rupture tests, including for comparison the short-time ultimate tensile stress curve, are illustrated in Fig. 14. These curves show the various stresses and temperatures at which failure will occur in 1, 10, 100, and 1000 hr. It can be seen that the rupture-strength curve for 1000 hr.

begins to fall abruptly at 350° C., and even for periods as short as 1 hr., further increase in temperature of no more than 50° C. causes rapid decrease in rupture strength. Despite the expectations there may have been in view of its high melting point, commercially pure titanium is not suitable for applications involving long-continued stresses at temperatures exceeding 350° C.

Joining presents numerous problems, many of which, especially those concerned with brazing and soldering and with the welding of alloys, are not yet solved. Commercially pure titanium can, however, be readily welded by electrical-resistance methods and also by means of argon-arc techniques, provided that precautions are taken to shield from atmospheric contamination not only the molten welded metal, but also all heated parts of the base metal, including the back of the weld. In the welding operation the metal runs easily, and there is no difficulty in consistently producing sound ductile welds of good appearance.

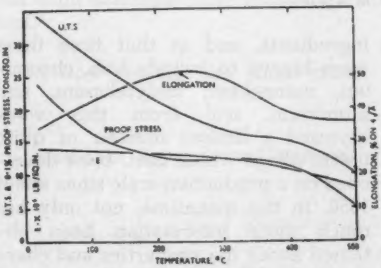


FIG. 13.—Short-Time Elevated-Temperature Tensile Properties of Commercially Pure Titanium.

The attractive strength: weight ratio is the feature of titanium and its alloys chiefly responsible for their demand and use in aircraft, but the other excelling characteristic of the metal is its resistance to corrosion. The early optimism about this has been abundantly justified, and a broad indication of it in comparison with a few other well-known metals is provided in Table I.

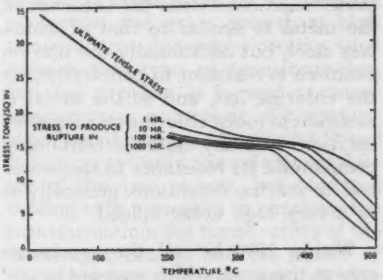


FIG. 14.—Elevated-Temperature Stress-Rupture Properties of Commercially Pure Titanium.

TABLE I.—*Resistance to Corrosion in Various Media*

Corrosion Medium	Titanium	Austenitic Stainless Steel	Aluminum	Copper
Cold 10% sulphuric acid	✪	★	★	✪
Boiling 65% nitric acid	✪	✪	★	★
Cold 5% hydrochloric acid	☆	★	★	✪
Cold *aqua regia*	☆	★	★	★
Boiling 20% acid chloride solutions	☆	★	★	★
Hot fatty acids	☆	✪	☆	✪

KEY

☆ Suitable for use where little dimensional change is tolerable; corrosion rate < 0·005 in./year.

✪ Suitable for use where some corrosion is tolerable; corrosion rate 0·005–0·05 in./year.

★ Not ordinarily suitable for use; corrosion rate >0·05 in./year.

This outstanding resistance to corrosion is attributed to the presence of a protective oxide film which is most stable in oxidizing environments, and

under such conditions the behavior of the metal is similar to that of stainless steel, but additionally the film on titanium is resistant to penetration by the chlorine ion, and so the metal is resistant to moist chlorine and aqueous solutions of many chlorine-containing compounds. Its resistance to sea-water and to marine conditions generally is of a very high order indeed.

Within 1000 hr. all the specimens except titanium, which was not sensibly affected, were completely penetrated over a considerable area. Furthermore, it is not corroded by fouling organisms in sea-water, nor is it corroded in this medium when it is coupled, for example, to stainless steel or cupro-nickel.

It is resistant to cold nitric acid up to 98% concentration, sulphur compounds, strong alkalis, many organic acids, chlorinated solvents, and cold *aqua regia*. It is not affected by most foods and food products, or by body fluids, and being non-toxic it could be used for many purposes in surgery. In those solutions which do attack the metal, such as certain hot strong acids, the corrosion always appears to be general without evidence of either intercrystalline or stress corrosion.

VII.—TITANIUM ALLOYS

As soon as ductile titanium became available, even in small quantities, attention was immediately turned to a consideration of alloying possibilities. In those early days, although they were only a few years ago, when little or nothing was known about the theoretical background or constitution of titanium alloys, this work was in the main of an *ad hoc* nature, and consisted largely of making and testing a great many alloys containing varying amounts of one or more elements that could conveniently be added to the metal, with the object of making a rapid assessment of the effect of such additions on the more commonly determined mechanical properties.

A lot of work of this type was carried out by a large number of research teams, but as titanium of various grades and purity and various methods of consolidation by powder compacting and melting were employed, it is not surprising that comparison and assessment of the different claims of the many alloy compositions was difficult. Nevertheless, it became clear from these investigations that some elements showed promise as alloying ingredients, and at that time these were known to include iron, chromium, manganese, molybdenum, and aluminum, and from this work emerged a limited number of quite useful alloys which have been developed on a production scale since about 1950. In the meantime, not only has much more information been obtained about the properties and characteristics of these alloys, but several new and extremely promising compositions are being developed as a result of recent and current researches on the structure and constitution of a great number of binary and more complex titanium alloys. Although this has led to a fuller understanding of the behavior and characteristics of existing alloys and pointed the way to new and improved alloys, it has also made it abundantly clear that the whole subject of the constitution of titanium alloys, quite apart from their technology, is a complicated one, and our present limited knowledge is itself an indication that a great deal yet remains to be found out.

The role which various alloying elements play is becoming more clearly defined. It is possible in this regard to

classify them into several groups on the basis of relative solubility in the two phases, but in considering them more generally and broadly it has been established that most of the metallic elements so far investigated, including iron, chromium, manganese, molybdenum, vanadium, tantalum, and niobium, depress the transformation, are more soluble in the β phase than in the α phase, and tend to stabilize it. Two metals, namely aluminum and tin, have just the opposite effect. They are more soluble in the α phase, with which they form substitutional solid solutions, tend to stabilize it, and raise the transformation. Other elements, such as oxygen, nitrogen, carbon, and boron, which form interstitial solid solutions have the same effect.

On slow cooling, the phase transformation takes place by a process of nucleation and grain growth at high temperatures, but rapid cooling suppresses this type of transformation, and the α phase is formed at lower temperatures as a result of a martensitic type of change. Alloying additions influence not only the relative stability of the two phases, but also the cooling rate necessary to suppress the transformation, the temperature of the martensitic change and the nature of the decomposition products of that change. Depending, therefore, on the amount and type of element or elements added, it is possible to produce alloys with structures consisting entirely of the α or β phases, or mixtures of these phases with or without such decomposition products as eutectoids, inter-metallic compounds, and others, the precise nature of which is not yet understood.

TABLE II.—*Approximate Compositions and Properties of α/β Titanium Alloys*

Alloy Type	Nominal Alloy Content, %						Condition	Typical Mechanical Properties		
	Cr	Fe	O_2	Mo	Mn	Al		0.2% P.S. tons/in.²	U.T.S. tons/in.²	Elongation, %
Titanium-chromium-iron	1.8	0.9	0.15	...	...	...	Hot-worked and annealed at 700°C.	35-45	50-60	15-25
	2.7	1.3	0.25	...	...	...		55-65	65-75	10-20
	3.0	1.5	0.5	...	...	...		65-75	75-85	5-15
Titanium-chromium-iron-molybdenum	2.0	2.0	0.2	2.0	...	...	Hot-worked and annealed	50-60	60-70	10-20
	4.5	4.5	0.2	4.5	...	...		55-65	65-75	5-15
Titanium-manganese	...	...	...	...	7.0	...	Annealed sheet	60-65	65-70	10-20
Titanium-manganese-aluminum	...	...	...	...	4.0	4.0	Hot-worked bar	60-65	65-70	15-25
Titanium-chromium-aluminum	5.0	...	...	...	...	3.0	Hot-worked bar	60-75	70-85	5-10

The sort of alloys that have so far been available are indicated, together with some room-temperature properties, in Table II, which is based on data from various sources. They are all much stronger but less ductile than commercially pure titanium, their tensile strengths and elongation, values ranging up to 85 tons/in. and 25% respectively. They retain their proper-

ties somewhat better at high temperatures and have superior creep properties. As a result of alloying, the superlatively good corrosion-resistance of the metal does not appear to be impaired, and, in general, the alloys possess the excellent fatigue and corrosion-fatigue properties that characterize the metal. Impact-strength values range from about 5 to 15 ft.-lb., according to composition, grain-size, structure, and impurity content, and although these are relatively low, they increase rapidly with temperature, values of 100 ft.-lb. being obtained with titanium-chromium-iron alloys at temperatures over 250° C., whilst alloys have been produced experimentally with room-temperature impact strengths of over 50 ft.-lb.. Although some doubt has been expressed about the notch sensitivity of high-

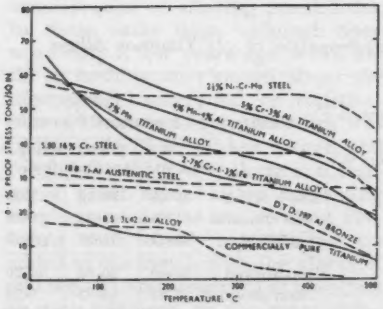

21% Ni.-Cr.-Mo STEEL
5% Cr.-1% Al. TITANIUM ALLOY
4% Mn.-1% Al. TITANIUM ALLOY
7% Mn. TITANIUM ALLOY
5.80 16% Cr. STEEL
2·7% Cr.-1·3% Fe. TITANIUM ALLOY
18/8 Ti-Al AUSTENITIC STEEL
D.T.D. 197 Al BRONZE
B.S. 3L42 Al ALLOY
COMMERCIALLY PURE TITANIUM
0·1% PROOF STRESS TONS/SQ IN
TEMPERATURE, °C

FIG. 15.—Effect of Temperature on Ultimate Tensile Stress of Commercially Pure Titanium and Titanium Alloys.

strength titanium allows, particularly when subjected to fluctuating stresses, recent evidence suggests that some at least of the duplex alloys are equal to or better than high-tensile steels in this respect.

Such alloys as those in Table II have essentially similar structures in as much as they consist of a mixture of the two phases. The quantity of β-stabilizing elements present are sufficient to effect the retention of some β at room temperature, and the presence of α stabilizers, such as oxygen, carbon, and aluminum, modifies without basically changing the mixture of α/β phases. The optimum mechanical properties of these duplex alloys are developed by hot working them in the tranformation temperature range. If the working is not continued down to comparatively low temperatures, there is a risk that some loss of ductility will result. Rapid cooling from temperatures above that of the transformation has an embrittling effect, so although these α/β alloys have shown themselves to be useful engineering materials, they are not suitable for welding.

Duplex alloys containing aluminum, having a considerably higher transformation range, permit of more latitude in hot-working conditions, and the presence of this element also has the important effect of increasing the strength of the α phase at elevated temperatures. They thus retain a greater proportion of their strength at temperatures up to about 600° C. than do alloys in which α stabilizers are not present or where the α phase is strengthened only by interstitial alloying elements and, moreover, they have improved creep properties. Recent evidence indicates that molybdenum may be a beneficial addition in improving ductility and strength at elevated temperatures. The short-time elevated-temperature tensile properties of several duplex titanium alloys with those of some other metals, are shown in Figs. 15-17.

Although all of the alloys which have so far been developed beyond the experimental stage are of the α/β type, attention is now being turned to single-phase alloys, since from results now being obtained it is evident that they, at least in certain respects, are

better than the duplex alloys. Thus alloys containing metallic stabilizers, such as aluminum or tin, in sufficient amount are not affected by cooling rate from high temperatures, and so are free from the limiting disadvantages which beset duplex alloys so far as welding is concerned. In addition to having improved properties at high temperature and being far less sensitive to hot-working conditions, such alloys, if stabilized by aluminum, have the further merits of lower density than alloys containing such elements as iron, chromium, or manganese, and improved resistance to oxidation which in hot working is a most useful attribute. It would thus seem that alloys of the α type may prove to have the best possibilities for high-tempature applications. On the other hand, they are less ductile and cannot be so readily cold worked.

The interstitial solutes which stabilize the α phase have a different effect on mechanical properties, for quite small additions give rise to pronounced hardening, and consequently marked changes result from small variations in alloy concentration. So far there has been no evidence to indicate that the addition of these elements alone would be likely to give rise to useful titanium alloys.

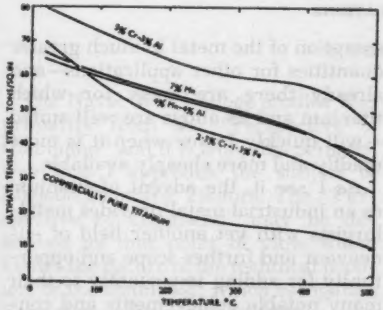


FIG. 16.—Effect of Temperature on Proof Stress.

Alloys composed wholly of the β phase appear to be much more ductile and to have a lower rate of work-hardening than single-phase α alloys, and are potentially therefore much more suitable for the manufacture of strip and sheet. Furthermore, fully stabilized β alloys, not being sensitive to rate of cooling, might be expected to hot work and weld as easily as α alloys. The development of satisfactory all-β alloys, however, presents many

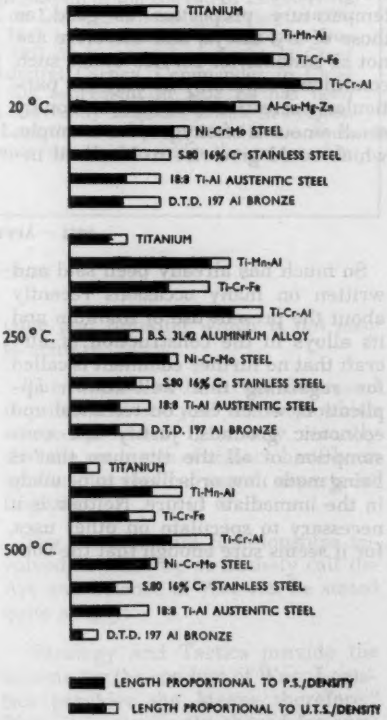


FIG. 17.—Ratio of Proof Stress and Ultimate Tensile Stress to Density of Various Alloys.

difficulties, several of which have not yet been resolved. For instance, in order to avoid the formation of embrittling martensitic decomposition products when the alloys are heated to quite low temperatures, the β phase must be thoroughly stabilized, and this necessitates the addition of substantial amounts of alloying elements. This, of course, increases the density, but what is more important, it results in the formation of a highly alloyed phase which is much less ductile than a less heavily alloyed but incompletely stabilized β alloy. Thus the desired cold ductility is seriously reduced by achieving complete stability. Alloys of this type would not be expected to have high-temperature properties as good as those of α/β alloys, and therefore are not so suitable for service under such conditions, especially as they are particularly sensitive to contamination by small amounts of oxygen, for example, which could give rise to localized instability and the formation of small amounts of embrittling decomposition products.

It is too early yet to suggest what the relative importance of alloys of different structural types might eventually be or to forecast the possible pattern of alloy development. The fact that in so short a time and in the almost complete absence of detailed basic knowledge, alloys, have been produced with a strength : weight ratio better than that of any other available material, is, however, I would submit, most encouraging and augurs well for the future. The additions that have been made to our knowledge in the meantime, and the clarifying information that is being obtained from current studies on alloy constitution and properties, warrant the confident expectation of much progress in the development of new alloys in the near future.

VIII.—APPLICATIONS

So much has already been said and written on many occasions recently about the present use of titanium and its alloys in the construction of aircraft that no further comment is called for regarding this well-known application, which can, on technical and economic grounds, justify the consumption of all the titanium that is being made now or is likely to be made in the immediate future. Neither is it necessary to speculate on other uses, for it seems sure enough that the consumption of the metal in much greater quantities for other applications—and already there are many for which titanium and its alloys are well suited—will quickly follow when it is more readily and more cheaply available.

As I see it, the advent of titanium as an industrial metal provides metallurgists with yet another field of endeavour and further scope and opportunity for adding importantly to their many notable achievements and contributions to progress in the past.

LOGISTICS PLANNING FACTORS

REAR ADMIRAL HENRY E. ECCLES, USN, RETIRED

BIOGRAPHY

Rear Admiral Henry E. Eccles, USN Retired was born in Bayside, Long Island in 1898 and after graduating from the Naval Academy in 1922 served in Battleships, Submarines, Cruisers, and Destroyers. A post graduate engineer he received his M.S. in Mechanical Engineering (Diesel) from Columbia in 1930 and from 1938 to 1940 served in the Design Section of the Bureau of Engineering (Ships). After mid 1942 he concentrated on Logistics Planning, serving in OP-Nav and with Service Force Pacific. In 1947 he established the Logistics Department at the Naval War College. In 1951-52 he served as Assistant Chief of Staff for Logistics on the Staff of Admiral Carney, Commander in Chief Allied Forces, Southern Europe. Since his retirement in 1952 he has been a consultant for The George Washington University Logistics Research Project. He is the author of "Operational Naval Logistics" NavPers 10869. He has been a member of the ASNE since 1938. This paper was written under the sponsorship of O.N.R. Contract N7 onr 41904.

INTRODUCTION

The Naval War College studies War primarily from the "Perspective of Command" and it is from this perspective that I approach the subject of Logistic Planning Factors. The "Perspective of Command" may be described as that point of view which knows the nature of the technical problem of the command; which recognizes how they affect its capabilities and which understands the amount of time and effort required to solve these problems. This knowledge is essential to the discharge of those inescapable obligations and prerogatives of command to coordinate the activities of technical assistants and to evaluate their recommendations. This "Perspective of Command" represents a balance of knowledge and thinking which is not easy to achieve.

The practice of the Art of Command requires a mastery of the tools which science provides. It is only recently that the resources of science have been applied to the command aspects of Logistics.

The Fundamental Relationships involved in what we so blithely call the Art and Science of War can be stated quite simply:

"Strategy and Tactics provide the scheme for the conduct of War: Logistics provides the Means therefore." Since it is manifestly absurd for anyone to presume to plan or to execute

a scheme of war without understanding and controlling the means for its accomplishment, two further principles naturally follow:

"Logistics is a responsibility of Command."

"A Commander must have the same control over his Logistics operations as he exercises over his tactical operations."

These principles are fundamental. If they are violated one of two results is likely:—military disaster may ensue, or victory will be attained only after unnecessary delay and with unnecessary waste of life and resources.

The study of Logistics has two aspects.

First, the Perspective of Command.
Second, the Technical Perspective.

This paper will deal primarily from the Perspective of Command, i.e., the planning of major operations, and the coordination of the work of subordinate commanders and technical specialists.

The planning factors that will be discussed will be those most useful to "Command." However, from time to time, I may touch on the planning factors that the technical specialists will use, for inevitably there is considerable overlap between these.

While some of the methods mentioned may be officially sanctioned and used, I will make no effort to follow or present any official doctrine. Official doctrines change from time to time; the basic facts, the basic problems, and the basic forces remain the same, regardless of any rules that High Authority may promulgate. It is only when these basic facts and forces are understood that the Commander can be the master rather than the slave of the tools of planning.

PLANNING FACTORS

All systems of Logistic Planning use Planning Factors of one sort or another.

Logistic planning factors have been prepared to simplify and speed up certain parts of the overall task of Naval Logistic Planning. If they are to do this, they must be used with discretion and with a clear understanding of their nature, their derivation, and their limitations.

Naval Logistic Planning Factors are arbitrary values which represent the quantitative relationships that exist between the composition and employment of naval forces on the one hand; and the availability, consumption or utilization of materials, personnel, facilities and services on the other hand.

These relationships may involve, time, distance, volume, weight, area, number of units of a commdoity, cost, life expectancy and other matters. They are used in planning supply, equipment, construction, personnel, transportation, and repair, salvage and hospitalization facilities.

Planning Factors may be merely the record of the personal experience of the planner written in a little black book kept in his hip pocket. In some instances, they may be taken directly from some official publication, such as the Navy "Logistics Reference Data" or the Army Field Manual 101-10, in other instances they may be the results of recent surveys or analyses, the results of which have not yet been officially published. To be most effective, planning factors should be a group of factors based on a detailed scientific study and evaluation of many types of situations.

This scientific study requires the understanding cooperation of the fleet on all levels from Fleet and Type Commanders down thru The Ship Heads of Departments.

All planning factors are based on experience or usage data, some of it good, some of it very poor; some of it obsolete, some of it up-to-date. Therefore, some of our planning factors are quite accurate and some are hardly better than wild guesses.

Planning Factors do not become good planning tools unless the planner knows the circumstances under which the fundamental usage data on which the factors are based were collected and processed.

If we can devise methods and factors that are suitable for various types and levels of planning, we will have done much to simplify the problem. However, we cannot expect too much simplification. Logistic planning will always be a difficult task, a task that challenges our best abilities. Planning Factors—regardless of how carefully they may be prepared can never be a substitute for imagination and good judgment.

Prior to World War II the Army had its Field Manual 101-10 which gave planning factors for various organizational units and situations.

Up to World War II the Navy had practically no Logistic Planning Factors. While each Bureau had reams of data and factors pertaining to its own internal technical operations, very little of this was useful from the Perspective of Command. The ship characteristic cards and the publication of "Ship Characteristics" gave certain data as to speed, fuel capacity and fuel consumption and as to capacity of ammunition, food and stores, and some other matters. However, these data were not based on war conditions, and frequently were not accurate or properly coordinated. Each Bureau devised its own scheme for estimating its own technical requirements and made individual collections of data. There was little systematic exchange of information, no overall coordination, and on the whole, line officers took little interest in these matters.

During the War, most Naval losgistic planners prepared their own data as a result of their own personal experience. (The "Little Black Book" that always will be an invaluable supplement to the official logistic publications.) The major logistic requirements were based primarily on the guesses of individuals who were willing to stick their necks out and say, "This is It, this is what I want." There was no systematic correlation of usage and purchase, and there was very little attempt to collect accurate data. At one time even, The Deputy Commander Pacific Fleet, in disapproving proposals to obtain better reports from advanced Naval Bases, said that the Navy was too busy working to make reports, while the Army was so busy making reports it couldn't get much work done.

Since there were no data or planning factors it was not possible to make studies of the real cost of advanced shore bases versus floating support. Hence, it was assumed that it was faster and cheaper to build advanced bases rather than logistic support ships. However, post war studies indicate that in a majority of instances the reverse is true.

During the war there were certain particularly significant developments which lead to improved planning systems and planning factors. In late 1942, the Logistics Plans Division of the Office of the Chief of Naval Operations was reorganized under Rear Admiral Oscar Badger. All logistic planning was brought under his coordinating control, and an orderly system of records was set up.

The Catalog of Advanced Base Functional Components was developed in 1943; this systematized and broke down into manageable units the huge advanced base projects; the Lions, Cubs and Acorns.

The Bureau of Ships and the Bureau of Supplies and Accounts collaborated in setting up a Technical Spares Depot at Mechanicsburg in which usage, procurement, storage and distribution, were seen as a whole.

The Bureau of Supplies and Accounts and the Bureau of Aeronautics systematized the distribution of aviation spares in the Aviation Supply System and in this developed the Supply Demand Control concept.

And finally, in late 1944, Commander Western Sea Frontier was set up as the coordinator for the logistical support of the Pacific Fleet which flowed through West Coast ports. However, most theater, fleet and task planning continued to be on the basis of personal guesses.

In 1944 and 1945, Commander-in-Chief Pacific Ocean Area; the Bureau of Yards and Docks; and the Bureau of Supplies and Accounts compiled some averages as to the various factors of man hours of effort involved in the building of various advanced base facilities and the Bureau of Ships started studies in the "Repair Equivalent Requirements of Various Types of Ships." Other Bureaus also did work on similar projects.

In 1946, the Chief of Naval Operations directed the Bureau of Supplies and Accounts, with the collaboration of the other Bureaus, to develop "Logistic Reference Data." That Bureau, using the Research Facility at the Naval Supply Corps School at Bayonee, developed the first edition then called "NavSandA 94." This was a compiliation of usage data and experience over a very wide variety of Naval Logistic Support categories. The other Bureaus collaborated.

As such, it was a great improvement over anything the Navy had ever had before, but it had many shortcomings. Several revisions since the first edition have greatly improved it and it now provides the working foundation for most Naval Logistic planning. However, Logistics Reference Data now published by OP-NAV as NWIP 11-21 still has certain shortcomings and, in many instances, the officers in the Fleet, the Bureaus and in OP-NAV depend on their own private records and evaluations to plan.

In 1947-48, the Logistics Department of the Naval War College, using the figures contained in Logistics Reference Data, made the first effort to compile "Planning Factors" which were aggregations of data useful for quick general estimates.

In 1949, the newly created Logistics Research Project of the George Washington University undertook the first scientific study of Logistics Planning Factors. At the same time, this same group started the development of an electronic logistics computer and in 1952 undertook the collection and analysis of usage data among ships which had taken part in Korean operations.

The foundation of good planning factors is good usage data. Since this is a self evident statement, it is interesting to note that the first overall scientific analysis of Fleet Usage Data was started in 1952. Up to that time, while certain individual technical items had been analyzed, no serious attempt had been made to correlate individual studies or to analyze the fundamental nature of the problem.

The result is that many of our present planning factors are based on usage data that is too broad for accurate planning. We know for example, how much of certain categories was shipped

to the Pacific for a given period, but we don't know what happened to the material. We don't know how much went for its designed use, how much was lost, or stolen, how much was wasted thru deterioration, or how much of the storage inventory aboard ship or in depots was necessary. Yet, the planning factors for Fleet use are based on the amount shipped rather than the amount actually used by the ships of the fleet.

Figure 1 illustrates the problem.

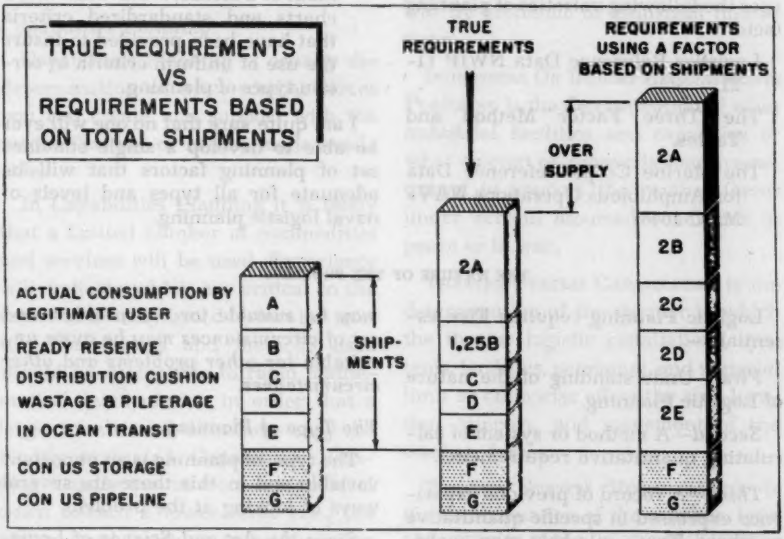


Figure 1

Take for example an instance where the number of ships is increased by 100% with no other major change in the operation. It is likely that consumption would be doubled but that ready reserve would have to be increased 25% to handle the situation—and the other factors would not change.

The true requirement would be $2A + 1.25B + C + D + E$.

If on the other hand we use a factor based simply on overall shipments we will come up with a requirement of $2(A + B + C + D + E)$.

Our present factors do not always make this distinction, hence their blind use may result in tremendous over supply and the build up of the Logistic Snowball. This explains why so many planners rely wholly on the Little Black Note Books in their hip pockets.

In 1950, the Logistic Research Project evolved the Three Factor Method of planning.

Since 1951, both the War College and CinClant have used this method in some of their work and have collaborated with the Logistics Research Pro-

ject in its further development. Several months ago, Op-Nav requested that the Project submit a revision of the Three Factor Method as applied to resupply requirements in order that it may be distributed to certain commands for test and comment.

As of today, therefore, the Navy uses the following varieties of planning factors.

Logistics Reference Data NWIP 11-21.

The Three Factor Method and Tables.

The Marine Corps Reference Data for Amphibious Operations NAVMAC 1048.

Bureau Publications and Manuals.

Privately Prepared Charts, Tables and Little Black Books.

Army Field Manual 101-10.

Air Force Manual 400-5.

An uncertain number of Department of Defense, J.C.S. and NATO charts and standardized criteria that have been provided to insure the use of uniform criteria in certain types of planning.

I am quite sure that no one will ever be able to develop a single standard set of planning factors that will be adequate for all types and levels of naval logistic planning.

THE NATURE OF THE PROBLEM

Logistic Planning requires Five essentials—

First—Understanding of the nature of Logistic Planning.

Second—A method or system of calculating quantitative requirements.

Third—A record of previous experience expressed in specific quantitative numbers. These numbers may represent either evaluated analyses or raw averages.

Fourth—The exercise of skilled professional judgment in the selection of the system and the manipulation of the numbers.

Fifth—Complete integration of Logistical, Strategical and Tactical Planning at all levels of command.

Logistics planning is a series of approximations, compromises, and refinements, the nature of which will change in accordance with certain variables. These are: the type of planning, the level of planning, the range and timing of planning, and finally, the nature of the combat situation facing the planner. *The Methods and Factors which may be suitable for one problem and set of circumstances may be quite unsuitable for other problems and other circumstances.*

The Type of Planning

The type of planning is an important variable and in this there are several ways of looking at the problem.

Since the Art and Science of Logistics is not yet fully developed there may be some differences of opinion as to the precise terminology which should be used to define these different types of planning. However, the differences are real and in general follow the descriptions given hereafter.

One approach is to consider that in logistics there are two very general types of planning, the first of which may be called "Logistic Planning." This may be considered as an analysis of the relevant logistic factors in a situation. The analysis is made in order to reach a decision as to a strategic or tactical course of action. The other may be called "Planning for Logistics" or "Planning for Logistics Support." This is the planning of the details of the

logistic support required to carry out the decision which was previously reached.

Another point of view breaks the subject into two broad types, "Capabilities Planning" and "Requirements Planning."

Capabilities Planning

Capabilities Planning is usually the determination of what combat forces you can create and support with the means that are or can be made available.

In Capabilities Planning it is likely that a limited number of commodities and services will be used. Experience will indicate which are critical to the decision. Usually broad factors are useful. The factors and methods used should be susceptible to rapid mathematical manipulation in order that a large number of situations may be readily evaluated. Capabilities Planning usually moves from a high level down toward a lower level (i.e., the higher level is trying to estimate the effect of certain limitations on the capabilities of subordinates).

Requirements Planning

Requirements Planning differs from capabilities planning in that it is the process of determining what must be procured in order to carry out a specific course of action with specific forces. It would appear that the planner is on the same street as in Capabilities Planning — but he is going in the opposite direction. He starts with the forces and scheme and works up through the levels of command in order to determine what must be produced or budgeted.

INDUSTRIAL OR BUDGET CAPABILITIES PLANNING is a determination of how the procurement and production capabilities of the nation limit or otherwise affect the build-up and logistic support of the combat forces. In peace this is determined by budget limitations; in war by economic or industrial limitations.

INDUSTRIAL OR BUDGET REQUIREMENTS PLANNING is the determination of what industrial facilities and capacities or what amount of appropriations are required to support the combat forces under certain assumed conditions in peace or in war.

THEATER SYSTEM CAPABILITIES is the determination of the manner in which the theater logistic installations, systems, facilities, personnel, and material limit or otherwise affect the size, location, support, and movement of the combat forces.

THEATER SYSTEM REQUIREMENTS is the determination of the number, type and capacity of the theater logistic systems, etc., under certain assumed conditions.

THEATER ITEM AVAILABILITY is the determination of how the availability of supplies in the theater affect the support and movement of the combat forces.

THEATER ITEM REQUIREMENTS is the determination of the requirements for certain specified items of supply to support the operation of the theater combat forces under certain assumed conditions.

Thus, it will be seen that Budget Planning, Industrial Planning, System Planning or Item Planning can be done either on a capabilities or requirements basis.

LOGISTICS PLANNING FACTORS

THE VARIABLE FACTORS

LEVEL, RANGE, AND NATURE OF SITUATION

The level of planning has a very important bearing on the method and factors used in planning. At low level, precise factors in relation to very specific items are usually required. At the highest level, since the use of detailed factors for each element of the plan causes intolerable delay, very broad factors are used to make general aggregations of commodities and equipments. These broad factors, however, must be accurate enough to give assurance that the lower levels charged with detailed development of plans will receive feasible broad plans. One of the major problems in high level planning of either capabilities or requirements type is that of developing planning methods and factors by which many different situations and assumptions can be rapidly evaluated in terms of their logistics implications.

The range of planning has an important effect on the choice of methods and factors. Normally, short range planning calls for much more specific methods and exact factors. In long range planning more room for give and take is permissible, particularly in relation to the time element.

Closely related to the question of range is the question of the nature of the situation.

Is it stable? That is to say, is the level of activity reasonably constant over a long period of time. If so, the problem is similar to the question of SUPPLY MANAGEMENT with its associated elements of Stock and Inventory Control.

Is the situation unstable or fluctuating? Are we fighting a defensive, retreating action with all its unpredictable losses of material? Or, are we fighting an offensive, advancing action, with all its problem of steady expansion of effort and with periodic build-ups to support specific operations? In either case, the problem becomes more complex and the maintenance of adequate reserves and flexibility is both important and difficult. Speed of planning is very important, and important decisions in one logistic category may require quick, if broad, estimates of requirements in another category. *The factors and methods which give great economy in a stable situation may not be adequate for the changing situation.*

THE METHODS OR SYSTEMS OF LOGISTIC PLANNING

One method commonly used is LINE ITEM planning. This is the handling and processing of each item of supply and equipment as an individual and specific task. For example, a case of soap, an armature for a generator, a small boat propellor, are all line items. For certain situations this is the most reliable and efficient method. However, in high level planning it requires so much time and detail that Strategic and Logistic Planning cannot be concurrent.

Another method of planning involves a so-called THREE FACTOR METHOD. In this, three factors, "Activity," "Conversion" and "Judgment" are manipulated to determine requirements of individual items or certain aggregates or groups of items under a variety of circumstances. In its present state of development this method appears immediately useful in major task forces, and theater, or higher level commands, for obtaining approximate requirements in selected categories, and for certain types of high level "Capabilities Planning," and in "Logistics Planning."

The following brief explanation of

the Three Factor Method will be helpful at this point.

The basic equation of the Three Factor Method is: Requirements= Activity Factor x Conversion Factor x Judgment Factor.

The *Activity Factor* is the measure of the level of an activity upon which one or more consumption rates depend. The Activity Factor is given in tables which reflect the best possible analysis of past and current usage data.

The *Conversion Factor,* also taken from tables, is a device to translate a single activity factor into consumption rates of one or more commodities or supplies.

Both the Activity Factor and the Conversion Factor are designed to permit the use of high speed computing equipment.

The combination of Activity Factor and the Conversion Factor give to the planner an estimate of the requirements for his forces under the assumption that they be operated under the so-called "Standard Conditions." If the planner considers that these forces will operate under these same conditions he uses a judgment factor of one. However, so-called "Standard Conditions" are almost never encountered and hence the judgment factor will be selected by the planner to conform to his personal professional estimate of how the actual planned operating conditions will vary from "standard."

To facilitate this, at the top of each table certain standard conditions are stated. These state in general terms the following conditions which the basic activity factor represents: type of employment, degree of enemy opposition, tempo of employment, climate, sea, wind, and percent of complement on board.

No matter what the numerical value of the judgment factors may be, the three factors are suitable for very rapid and simple manipulation to give quantitative requirements. As experience is gained in the use of these planning factors, many changes can be expected. New areas of usefulness will be discovered and better statements of so-called "Standard Conditions" will be made. Certainly the actual figures of the Activity Factor will be changed as more usage data are analyzed.

Between these two different approaches, one: that of detail; the other, that of broad aggregation, we find many different, methods of planning, none of which has been formally described.

WHERE WE NOW STAND

1. The basis for all strategic planning is the knowledge that you can support the combat forces in the scheme of maneuver proposed. This is based on the determination of requirements which are in turn based on planning factors. Since all strategic plans and all BUDGET ESTIMATES are based on LOGISTIC PLANNING FACTORS of one sort or another there is an urgent need for their improvement. This improvement can come only thru research and the

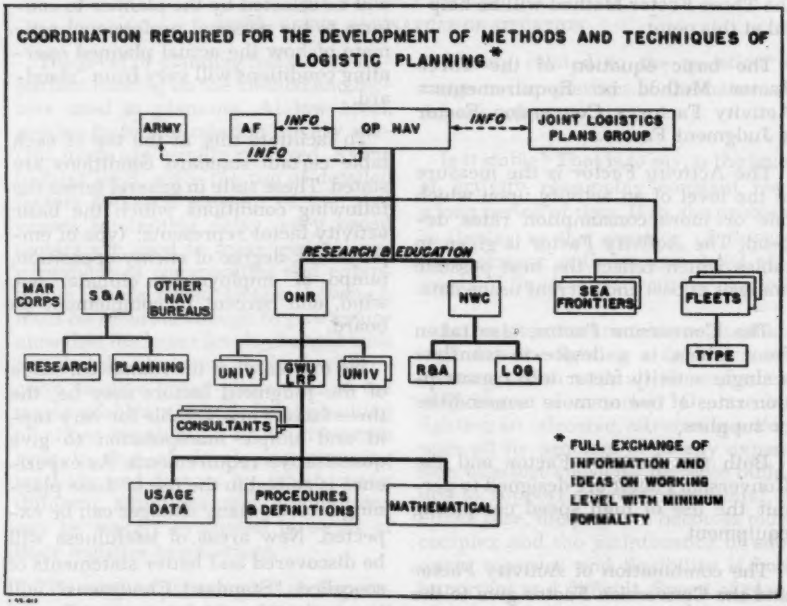


Figure 2

free exchange of ideas and experience between the interested agencies as shown in Figure 2. There is not yet an adequate exchange of opinion and experience in the development of planning factors.

2. No two major commands in the Navy use the same system and the same planning factors. Logistics Reference Data, NWIP 11-21, is very widely used but is frequently modified on the basis of the private guesses of individual planners. For certain purposes, CINCLANT uses the Three Factor Method and Tables and is collaborating in their improvement. CINPAC seems to be depending primarily on LINE ITEM PLANNING.

3. Each command must always maintain a systematized group of special data and planning factors which are peculiar to its own situation and the commander himself should be generally familiar with these. This becomes particularly important in the preparation and review of requirements in the chain of command.

4. It is important to distinguish between the method or system of using planning factors and the actual numbers which may be used with the system in making a specific plan. A good system or technique will be useful with an ever changing set of numbers.

The numbers themselves must be subject to continual review and improvement in accordance with the best experience data.

The planner must know the basic

conditions that the numbers in the factors reflect.

6. There never will be a system of planning and factors so perfect that combat commanders will have precisely what they need, no more or no less. There will always be excesses and deficiencies.

We can hope to:

A. Reduce the excesses so as to avoid sinful waste and to avoid reducing mobility and flexibility by overburdening ships and troops with useless supplies and equipment.

B. Reduce deficiencies to the point that they can be endured by resourceful personnel without reducing sustained fighting power.

C. To accomplisch these there must be:

Leadership.

Organization.

Sound Planning

Supply Discipline—That is: "Controlled Usage" and "Cost Consciousness."

The Ability to Improvise

6. Logistics planning is a series of approximations, compromises, and refinements, the nature of which will vary in accordance with the Type of Planning, The Level of Planning, The Range and Timing of Planning and the Nature of the Combat Situation.

There is no likelihood that anyone will evolve a single system or method of planning, or a single system of planning factors, that will suit every situation. A method of planning which may be suitable for one problem and set of circumstances may be quite unsuitable for other problems and circumstances.

7. If we can perfect our logistic planning systems and factors we can make specific improvements which will have accumulative effect in reducing the Logistic Snowball.

We can improve strategic and tactical plans.

We can save planning time.

We can reduce staffs.

We can gain in flexibility.

We can gain in mobility.

We can cut down waste.

We can improve our fighting power.

8. If we are to make these gains, there must be understanding and cooperation on the part of Ship and Type Commanders in the gathering and analysis of usage data and in the improvement of planning methods and planning factors.

9. Finally, A good logistics planner is not wedded to any particular planning system or planning factors. He uses methods and factors in the same way that any craftsman uses his tools and his materials. That is to say, he understands their capabilities and he selects them and uses them in the manner in which his professional judgment tells him is most appropriate to the task at hand. Our problem is to learn more about planning methods and planning factors in order that the planners of tomorrow will have better tools. There is no perfect way of fighting a war. Victory comes, not to him who makes no mistakes, but to him who makes the fewest big mistakes. It will only be through study of, and reflection upon, the problems of war in all its aspects of "Command," "Strategy," "Logistics," and "Tactics" that we will be able to follow the precept of John Paul Jones ". . . To do the best we can with what we have at hand."

PATENTS, PROGRESS AND PROSPERITY

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WHAT PATENTS ARE AND WHY WE HAVE THEM

The men who wrote our Constitution and our laws thought it was important to have improvements made in the things we use for our daily living and in our ways of doing things—what they called "the useful arts." And, so believing, they did something about it.

What they did was based upon the idea that the way to get the useful arts improved is to offer a fair inducement to those able and willing to make and disclose the improvements. That still sounds like pretty good horse-sense. The inducement offered is what we call a patent—a document by which the government grants to the patentee the right to exclude all others for the next 17 years from practicing the invention which has been disclosed and claimed. A copy of the disclosure of the invention is attached to the grant.

It is not surprising that our forefathers thought that the useful arts needed encouraging. Men had not been doing so badly in such things as architecture, music, painting, sculpture, literature, etc., but in all history they had done very little for the useful arts and even some of the things that had been discovered had become lost arts for want of disclosure and permanent records. The thing we call the "standard of living" was low and all but stationary. What we have today is the result of a tremendous spurt in improvements in the useful arts since about 1790—some big ones and thousands upon thousands of small ones. Over 2½ million patents on inventions have been issued in this country since that date. While our physical standard of living cannot rate in importance with our moral standards and spiritual standards, most of us would probably agree that our physical living standard of today is worth having—and worth improving.

The arrangement under which a patent is issued in this country has been called a contract, and correctly so. A contract results from an offer and an acceptance. Here we have a standing offer (stated in the patent law) to grant a patent to anyone who first makes and discloses an invention. The offer is accepted by the inventor when he applies for the patent and makes the disclosure.

Thus it is clear that the patent is a payment by the Government for the

public service rendered by the inventor in making and disclosing the invention. It is to be noted, however, that this "payment" is of a unique kind. It has no monetary value except what the inventor (or his representative) can put into it by commercializing the invention before the patent runs out. This value may be great or small, or, as often happens, nothing at all, depending in each case on the merit of the invention and the skill and energy used in promoting it.

In actual practice, the patent turns out to have some other remarkable and valuable effects, as we shall see presently, but the point here is that it is a payment for the making and disclosing of an improvement in the useful arts and so is the property of the patentee and is intended to be used for his benefit just the same as if the payment were in money.

The Way the Law Puts It

Among the relatively few powers delegated to Congress by the Constitution was the one authorizing copyrights and patents. It reads:

> *Congress shall have power . . . To promote the Progress of* Science and *useful Arts, by securing for limited Times to* Authors and *Inventors the exclusive Right to their respective* Writings and *Discoveries*
>
> *(The words applicable to patents are here italicized.)*

One of the first acts of the first Congress under the new Constitution was to pass a law exercising this power by providing for the grant of patents to the inventors of new things. Details of the patent laws have been changed from time to time, but they have never been repealed and they have never offered to inventors anything but an unencumbered "exclusive right" for a term of years. The wording of the latest revision of the law is:

> Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefor, . . .
>
> Every patent shall contain . . . a grant to the patentee, his heirs or assigns, for the term of seventeen years, of the right to exclude others from making, using, or selling the invention throughout the United States . . .

Other clauses of the law provide for the granting of patents on ornamental designs for articles of manufacture, and on new and distinct varieties in plant life.

It will be noted that the Constitution leaves it to Congress (a) whether to provide for patents at all, (b) if so, to name the classes of things which can be patented (within the useful arts) and, (c) to fix the amount of the offered reward by naming the length of the "limited times."

The *character* of the reward, however, is *not* left to Congress. The Constitution fixes that by providing that it shall be a period of "exclusive right" to the new discovery itself. Should Congress undertake to promote the useful arts by some other type of payment, it could find no constitutional authority for its act.

THE MAGIC OF THE "EXCLUSIVE RIGHT"

It is surprising, in a way, that the authors of the Constitution should have specified an "exclusive right" as a payment to encourage invention. They were monopoly haters, having lately suffered under monopolies granted by the British Crown for various common articles of commerce. Why did they not offer money awards, or land or honors to inventors, instead of a period of exclusive right to their respective inventions?

Experience has shown so many advantages in granting the period of exclusive right, as compared with a monetary award, for instance, that one wonders whether our ancestors could have foreseen them all.

First, it automatically matches the size of the reward to the size of the inventor's contribution to the public good, as nearly as this is humanly possible. If the invention is of great value, the public will be ready to pay the inventor well for the use of the invention, during the term of the patent. If it is of but small value to the public, the inventor can collect only a small amount from its use or sale.

Second, it requires no draft on the taxpayers' money to provide the reward. In fact, even the administrative costs have in general been covered by fees charged the inventor.

Third, it is an incomparably greater incentive than any feasible cash payment or like award could be, for the simple reason that nearly every inventor rates his own invention as very wonderful and highly important. It is his own creation. The prospect of an exclusive control of his own invention for a period of years makes him feel rich.

Fourth, the exclusive right serves to get onto the market new inventions which otherwise would be left to die. Putting a new thing onto the market usually requires a lot of experimenting, engineering, designing, trials and redesigning to get it into a shape acceptable to buyers and economical to make; and often a lot of sales promotion. It is what Charles Kettering called the "shirt-losing stage" because it costs so much while no returns are coming in. No one is likely to go to this trouble and expense and take the chances involved unless he has assurance that others cannot copy his product when it is finally in shape, and so, with no preliminary expense, under-[illegible] him in the market. The exclusive right of the patent gives that assurance. A cash award to the inventor would not.

Fifth, contradictory as it may seem, the patentee's exclusive right induces the most beneficial kind of competition we can have; namely, competition in making improvements in the useful arts. If there were no exclusive right each business rival would straightway copy any improvement made by any one of the others, so that shortly none of them would go to the trouble and expense of making improvements at all. *With* the exclusive right, when one rival improves his product by an invention, each of the others, knowing he cannot copy *that* improvement, must hustle around to find some other improvement as good or better so that he can stay in business. That is the kind of competition that has put us ahead of the world in the useful arts.

Sixth, quite aside from competition, the patent right is a strong spur to business enterprise because the only way a patentee can collect the reward for the patented contribution to the useful arts is to make and sell the improvement (or the product of the improvement, if it is a process) while his exclusive right lasts. A monetary payment to the inventor could not thus stimulate business enterprise.

Not only would a system of money rewards for inventors lack all of the advantages just named, but it would be impossible to administer fairly or effectively. Who could know at the time the invention was disclosed what its value to the public would prove to be? Even in the few cases where an estimate might be made of prospective savings per year due to an improvement, no one could know how many months or years it might be before some other invention would make obsolete the one whose value we are

trying to appraise. To wait until after the public's use of the improvement had ceased would not help much because we would still be left with an intricate and costly accounting job, often impossible to do at all. Also it would fail because the prospect of such a deferred and uncertain reward would be little or no incentive to invent. The cost of trying fairly to administer a pecuniary award system would be so great that it would be likely to exceed the cost of the awards themselves.

Consideration of alternatives to the exclusive right only serves to point up the virtues of the patent system as we have it. Dr. Karl T. Compton said of our patent system:

"The patent system itself is fundamentally one of the greatest social inventions which has been made for the benefit of the human race."

WHAT IS REQUISITE TO THE GRANTING OF A PATENT AND WHAT IS IT LIKE?

First, of course, there must be an invention if one is to get a patent, and that means an idea of the complete operative mechanism or procedure for accomplishing the desired result; not just a general idea that such and such a thing would be a good thing to do or even a suggestion of the general way in which it might be done.

But, assuming an invention, the prime requisite for obtaining a patent upon it is a disclosure of it in permanent written form, usually with drawings. As already indicated, this disclosure is what the public acquires in exchange for the granting of the patent. This disclosure must be clear and full enough to enable anyone who is familiar with that type of thing to make or practice the invention after the patent expires. And it must draw the line definitely between the invention and what was old, so that the public can see clearly just what the patent excludes them from doing while it remains in force.

The disclosure is made by filing with the Commissioner of Patents in Washington an application for patent containing a specification describing the invention; and the line between what is old and what is new is drawn, partly by general statements in the specification, but particularly by one or more "claims" appended to the specification and which define the invention with great exactness.

It is also necessary for the applicant to make oath that he believes himself to be the original and first inventor of the thing claimed, and to pay a Government filing fee of $30.00 (plus $1.00 for each claim over 20) and another like Government fee if and when the patent is granted.

The Patent Office examines the application to see whether the disclosure is sufficient and whether the thing claimed is so different from what was already known that invention, rather than the mere skill of an artisan, was required to produce it.

The Patent Office must also determine whether the invention falls within one of the classes as to which Congress has authorized the granting of patents. Some things, as, for example, a way of doing business or a plan of travel, or a form of Government cannot be patented because Congress has not authorized patents on such things, even assuming them to be among the "useful arts." Foods and medicines falling within the class of "compositions of matter" may be patented in this country, though they may not be, as such, in many foreign countries.

The recent Atomic Energy Law withdrew from patent protection certain inventions relating to that subject.

Applications for patent must be made in the name of the actual inventor or inventors. A patent cannot be granted to a corporation or company except as the assignee of a named inventor.

Patents run for 17 years from the date of the grant and (save for extensions to veterans) cannot be renewed or extended except by special act of Congress — which rarely happens. Originally, the patent term was 14 years—adopted from the British practice of the time—but after considerable experience the term was extended in 1861 to 17 years. This is reputed to be a compromise between the original 14 years and a 20 year term advocated by some.

As soon as the patent is issued, printed copies of the disclosure—the specification, claims and drawings—may be purchased from the Patent Office by anyone at 25c a copy.

If, during the life of the patent, anyone makes, uses or sells the patented invention without permission of the patentee, the infringer is subject to suit in a Federal court for an injunction to stop such infringement and for damages to the patentee caused by it.

IS THE AMERICAN SYSTEM OF PATENTS ANTIQUATED?

The basic principles of our patent laws have remained unaltered for 160 years. In that time the whole character of American industry has changed. We now have big corporations, huge and intricate machines, assembly line production, and inventions of types not dreamed of in colonial days. Thefore, some have suggested the old patent system cannot possibly fit modern conditions and should be thrown out or basically altered.

This sounds plausible enough at first blush but a little reflection shows that there is no truth in it. It is very much like saying that the use of money is obsolete by reason of these same changes in industry and so should be wiped out. As we have seen, a patent is merely a medium of exchange—a payment for services rendered in making and disclosing the invention, and so an inducement to more services. The patent law then is no more out-of-date than it is out-of-date to pay the employees of these big corporations and the men who plan the intricate machines and the men on the assembly lines.

The patent law has no relation whatever to the size of corporations or to the intricacy of machines or to the forms of business enterprise. It is related only to human nature—man's fondness for being paid for his work and his urge to improve his condition—characteristics which haven't changed much since 1790. The patent law is a plan for harnessing the horsepower of man's self-interest to the cart of public benefit. Perhaps the time will come when men will be able and willing to spend their time and effort in improving the useful arts for the benefit of the public unselfishly and without pay, but until that time comes we had better hold on to our patent system.

A corporation can do nothing with patents that an individual cannot do. The patent right is only the right to exclude others for 17 years from practicing the particular invention covered by the patent. From the public's point of view, it is immaterial whether the excluding is done by an individual or by a corporation. In either case the public gets full use of the invention without further payment at the end of the patent term, so the public's con-

tract with the patentee is fully carried out.

Of course, while the patent lives it may be the subject of dealings which—as dealings—may be in conformity with or in violation of the general law. A patent is a piece of property (as the Supreme Court has repeatedly and uniformly held, and as expressly declared in the new codification of the patent law). Also it is assignable (as expressly provided by law—and if it were not, it would lose much of its value as an incentive because few inventors are equipped to promote inventions commercially themselves). As assignable property, then, patents may, of course, be accumulated or used in ways which violate law, just as money or other property may. The cure for such abuse, whether by a corporation or an individual, is enforcement of the law violated, not destruction of the property misused, or denial of the right to hold such property.

The relation of patents to the antitrust laws is covered in a later section. The point here is that there is nothing in the existence of large corporations or "big business" which makes obsolete or impairs the usefulness of the patents as we have them. On the contrary, the advent of the modern corporation with its research laboratory has given the patent law a range for its beneficial operation beyond the fondest dreams of a hundred years ago.

The purpose of the American system is to get improvements made and disclosed—as many as possible, and as soon as possible. The patent law is not concerned with *how* they are made or *who* makes them—or *who* owns the patents. When corporations hire able men to make the inventions and furnish them with modern and costly laboratory equipment to help them do it, the companies are acting entirely within the spirit, the letter, and the purpose of the patent laws, and are doing it in a way for which America has reason to be thankful. In no other way could we have had most of the really great advances in the useful arts that have come in the last fifty years.

Except in a few rare instances, it is not a big corporation's patents that keep others from entering into competition with it. It is the corporation's energy, enterprise, public good will and momentum that makes a new competitor's start hard—when it is hard. So far as patents are concerned, anyone today is free to make, use and sell the same shoe-machinery, electrical appliances, or telephones that we had 17 years ago, for the patents on them have run out; and we all thought we had pretty good equipment in those fields in 1936. So far as patents are concerned, a newcomer able and willing to make and patent better improvements on the old things than those made by the people already in the business, could quickly take the business away from the old concern. If a new would-be competitor is not able to do that, or is not willing to spend the money and effort necessary to do it, there is surely no reason why he should receive gratis the right to use the improvements made by the company in the business which has spent its money and effort to make them available.

ARE PATENTS A NEEDED INDUCEMENT?

We are sometimes told that patents aren't really much of an inducement anway—that inventing is mostly automatic and inevitable and that war or other necessities supply what inducement is needed. Of course, there is no way to prove such a statement. The most that can be done is to show that

a particular invention here or there came without benefit of patents, but such inventing, through centuries of recorded history did little for the useful arts and left the standards of living scraping bottom. What we are interested in is the reason for the flood tide of inventions that we have had in the last hundred and sixty years or so, and which really have done something for man's standard of living. As to this the evidence is all against the suggestion that inventions will come as well without patents.

It is no accident that all of the countries with advanced technologies have patent systems. And it is particularly significant that the country which far outstrips them all—the United States —has the best patent system.

The test of the quality and sufficiency of a patent system is its effectiveness in getting inventions made and disclosed and onto the market, and by this test we lead the world. Our patent law is the best because it offers not only the right kind of inducement but *enough of it.* In this country the inventor gets the complete unencumbered right to exclude others for 17 years; no "ifs" no "buts" and no periodic renewal tax to keep it alive. In all of the leading foreign countries the continuance of the right to exclude is conditioned upon specified conduct by the patentee and is dependent upon the payment of annual renewal taxes, usually increasing as the years go by. So we offer a better price than the others. What is the result?

In testifying before the Temporary National Economic Committee in 1939, Patent Commissioner Conway P. Coe gave comparative figures for the patents issued by the leading countries of the world during the period 1930 to 1937 and showing the percentage of these issued to the citizens of the respective countries. (TNEC Exhibit No. 213) By relating the figures to the populations of the several countries we have an indication of the degree of stimulation which the patent law of each country has upon its own citizens. It thus appears that in the six countries issuing the most patents the annual average per capita patenting of inventions in home countries was approximately as follows:

In United States, one patent for each 2,900 citizens.

In Germany, one patent for each 5,200 citizens.

In France, one patent for each 4,200 citizens.

In Britain, one patent for each 5,000 citizens.

In Italy, one patent for each 11,300 citizens.

In Canada, one patent for each 12,200 citizens.

The yearly average for the five foreign countries is one patent for each 7,580 citizens so that our patenting rate—per capita—is more than 2½ times as great as it is for the others.

Could it be that offering a fair price for the goods has something to do with their production and delivery? Could it be that patents are indeed an effective stimulus to the improvement of the useful arts? Both theory and experience indicate that they are, and from the first that has been the conclusion of those best qualified to judge the efficacy of our patent system. Thomas Jefferson said:

"The issue of patents for new discoveries has given a spring to invention beyond my conception."

Mr. Bally, visiting this country from Switzerland in 1876, said in an address to his fellow countrymen on his return:

"I am satisfied from my knowledge that no people has ever made, in so

short a time, so many useful inventions as the American."

Abraham Lincoln said:

"The patent system added the fuel of interest to the fire of genius."

The writer of a New York times editorial (May 8, 1908) said:

"Yankee ingenuity became a byword the world over because of patent laws of unprecedented liberality."

F. D. Roosevelt said of our patent system that it

". . . has promoted countless applications of the arts and sciences to the needs and well being of our people."

The National Patent Planning Commission appointed by the President to make an intensive study of our patent system said in its report of June 1943:

"The system has accomplished all that the framers of the Constitution intended . . . it has . . . encouraged and rewarded inventiveness and creativeness, producing new products and processes which have placed the United States far ahead of other countries in the field of scientific and technological endeavor."

It is apparently clear to about everybody except a few critics that patents as we have them in this country are a great and valuable incentive to the advancement of the useful arts.

MUST THE ISSUED PATENT BE USED FOR PUBLIC BENEFIT?

The single purpose of the Constitutional provision for patents is, of course, to promote the progress of the useful arts. Any benefits to patentees is wholly incidental. Now and then someone will tell us that it follows from this that patentees, unlike the owners of other property, are bound, under the Constitution, to use their patents in a way that will promote the useful arts.

This impression is the result of careless reading of the Constitution. The Constitution does not say that patent holders are to promote the useful arts. It expressly says that *Congress* is to do the promoting. And it tells exactly *how* Congress is to do it; namely, *by granting* patents to inventors. Thus, it is the granting of patents for inventions that does the promoting sought by the Constitution, not something the patentees are required to do with their patents after they get them.

The authors of the Constitution no doubt expected that most worthwhile inventions would become available for public use during the term of the patent, and that is usually what happens because the only way the patentee can get anything out of his patent is by practicing the invention (or selling someone else the right to do so) while the patent lasts. That, however, is no part of the contract between the public and the patentee.

We have already seen that a patent is merely a payment for services rendered to the public, and once granted it is, of course, intended to be used for the patentee's own benefit just as much as if it were a hundred dollar bill. The public got all it asked for when it received the full disclosure of the invention with the right of free use after 17 years. In exchange the patent is given for the very purpose of enabling the patentee to make a profit for himself, if he can, during the time the patent lasts.

There is nothing in the Constitution nor in the statutes that puts any limitation upon the way the patent shall be used except such provisions as apply generally to the use of all kinds of property.

DO THE PATENT LAWS AND THE ANTITRUST LAWS CONFLICT?

Section 2 of the Antitrust Law of 1890—the Sherman Act—makes it unlawful for anyone to

"monopolize, or attempt to monopolize . . . any part of the trade or commerce among the several States, or with foreign nations."

Under the patent laws a patentee can, of course, and frequently does "monopolize" the entire trade in the particular thing covered by the patent.

An easy first impression is that the two laws must be in conflict, and it is quite commonly thought to be so. Indeed for more than a decade in the not too distant past, officials charged with enforcing the anti-trust laws and some with collectivist leanings did much to further the idea that such conflict does exist, and they have urged that, in the area of conflict, the patent law must give way because the anti-trust law is the "latest" expression of the public policy of the nation in regard to all monopoly. Since Congress has just re-enacted the patent law in strengthened form, *it* is now the latest expression of public policy and, on the same reasoning, the anti-trust law would not have to give way to the patent law.

However, the simple fact is that, properly understood, the two laws do not conflict at all. The trouble arises from vagueness in the anti-trust law.

The language of the patent law can be taken to mean just what it says. Not so the anti-trust law.

There is vagueness in the very nature of the thing the anti-trust law seeks to attain, as we shall point out in a moment. But aside from that it is obvious that even the word "monopolize" in the Sherman law cannot be taken in its broadest dictionary sense because to do so makes the law ridiculous at once. One of the meanings of "monopolize" is:

"To obtain or assume exclusive possession or control of." (Standard Dict.)

A horse breeder, of course, has exclusive control and so "monopolizes" all that "part of the trade" in horses which involves the sale or use of his horses. The same is true of the wheat grower with respect to the wheat he raises, and of the furniture manufacturer as to the furniture he produces. All of these people, therefore, and thousands of others, violate the Sherman law if it is to be read literally and without qualification. The courts do not so read it; and no one thinks for a minute of bringing suit against such "monopolizing" as we have just referred to.

The patentee of an invention is precisely on a par with the horse breeder. The patentee has exclusive control of the particular new invention covered by the patent—which, incidentally, like the horses bred on the stock farm, is something that did not exist before. There is no more reason for trying to stretch the Sherman law to cover the monopoly of a patentee than for trying to apply it to the horse breeder. Indeed, there is even less sense in it, for the patentee, in excluding others, has an express authority issued by the Government itself—namely the patent. It is not to be assumed that the Government issues an authority with one hand and at the same time with the other hand makes the exercise of that authority unlawful.

What the anti-trust laws seek to prevent is conduct by businessmen—and particularly, conspiracy between them—which has the effect of stopping or throttling competition in articles of commerce which would otherwise exist. This is discernible from the com-

plete wording of the Sherman Act* and the Court decisions construing it. The law is entitled "An Act to protect trade and commerce against *unlawful* restraints and monopolies." (Emphasis supplied.)

As already indicated, even this objective of preventing conspiracy and other acts which destroy normal competition is not clearly defined. In applying the law to actual cases the courts early found it necessary to point out that the law could not be taken literally to apply to every conceivable restraint of trade because every business enterprise necessarily constitutes some restraint on the trade of its competitiors. So the Supreme Court read the word "unreasonable" into the law by saying that it condemned only *unreasonable* restraints of trade. (American Tobacco case, 221 U.S., 108, 1911.) As thus construed, the law still leaves the businessman in a very uncertain position and wholly at the mercy of the court. What, with the best of intent, he thinks is reasonable the court may say is unreasonable.

Such being the nature of the antitrust law, the wonder is that it has worked as well as it has; and it was made to work fairly equitably until the late thirties and early forties, when there came a flood of suits based upon the vague law, and in which the directors and officers of many of the defendants, under threat of the criminal penalties of that law, were maneuvered into accepting "consent" decrees with harsh terms, which commonly included provisions effectively nullifving the patents of the company subjected to the treatment.

There is almost no course of action open to a fair sized and thriving business which can avoid an attack of this kind under the vague language of the law applied by an administrator who enjoys "big game" hunting for its own sake. If a company charges high prices and gets them, competitors will follow suit and it can be accused of combining with competitors "to monopolize" the market and mulct the public; if it reduces prices it can be accused of underselling the little fellow to drive him out of business, and so "attempting to monopolize" the market.

To "compete" in a commercial sense is, by definition, to vie with others to obtain the business patronage in some field by offering more in quality, terms or service. We all believe that such competition is a good, indeed, a necessary, thing in our economy. But we might as well realize that it is also a rugged thing. If we have real competition, the efficient and energetic will inevitably get the business and the bunglers or indolent will lose it. The only alternative is regimentation, governmental or private. We who believe in competition, then, must accept the necessary result—that some will lose, fail, be squeezed out. And we must not allow our laws, intended to encourage competition, to be so applied as to penalize a competitor the minute he fairly succeeds in the competition. The administrators of a law as vague and capable of abuse as the Sherman Act would do well to proceed with caution and deference and wholly without arrogance. The Sherman Law was not intended as an instrument for persecuting every successful business and it certainly was not intended as a tool for nullifying patents.

While it is clear, then, that there is no conflict between the patent law and the antitrust law, this, of course, is not to say that patents have not been *involved* in violations of the anti-trust laws. It is obvious that a patent, like any other piece of property, may be used as a bargaining chip in a combination or an agreement which vio-

*Title 15, U.S. Code S 1-7.

lates the anti-trust law because it unreasonably restrains trade. And this has happened—just as dollars and factories and a hundred others things have been so misused. It is, of course, the duty of the proper officials to stop such misuse. The evil in these cases, however, is in the conduct or the combination—not in the patent or the dollars or the factory—and the remedy is not to destroy the patent or the dollars or the factory, but to terminate the conduct, the agreement or the combination.

The aggregation of many properties in the hands of a single concern may or may not be the result of a combination in restraint of trade and this is as true of patent property as of any other. If there are only four known ways of making a commercial product and each one is covered by a patent held by one of four competing manufacturers of the product, the man who buys up all four patents to end the competition among the four businesses is almost certainly violating the anti-trust law. But a company may own thousands of patents without violating any law if the patents are the result of its own research work conducted in the course of an otherwise lawful business. Until the patents expire, there is no right to compete in practicing the new and patented inventions of anyone, lawfully acquired and used, no matter how many. All others are free to make their own improvements in the same art and anyone can take the business for himself by patenting the better improvements if he is able to devise them. All of the patents expire and the improvements become open to the public as their respective 17-year terms end, just as it was planned they should by the authors of the Constitution.

AS TO LICENSES UNDER PATENTS

A license under a patent is a permission from the patent owner to practice the invention of the patent—commonly granted in exchange for a royalty payment in some form. It is a partial surrender of the right to exclude others granted by the patent. This right of surrender is inherent in the property of the patent as in other property.

A license may be without any limitation at all; or it may be limited in a great variety of ways. Thus, one may grant a license to make and sell only 1,000 of a patented article, or to practice the invention only in the state of Connecticut, or to use the invention only in the manufacture of furniture, or to use only two of the patented machines and only in Haverhill, etc.

Such limitations have been put into patent licenses from the very earliest times. The law reports show adjudications of limited licenses going back for at least 100 years. And such limitations were upheld by the courts.

There have in the past been those who opposed all limited licenses. The reasoning went something like this: The patent law makes no mention of licenses (which is true). Therefore, a license agreement is to be judged under the general law. If a licensee's activities in trade are restricted, then, the license agreement is one in restraint of trade and is condemned by the Sherman law.

The error of this theory springs from a failure to understand what a patent is, and can be exposed most easily by looking at a concrete example of a limited license. Mr. Baker, let us suppose, is in the baking business. He invents and patents a mixing device which speeds up his operations and improves his product. Mr. Waters

makes washing machines. He finds he can use Mr. Baker's patented mixer to advantage in his machines and asks for a license to do so. That suits Mr. Baker alright, so he gives Waters a license "to make, use and sell the mixer throughout the United States in and for washing machines. No other license is granted." And Waters agrees to pay Baker "a one dollar royalty on each mixer he makes or sells."

Under that arrangement, it is plain enough that Mr. Waters cannot use Mr. Baker's invention in conducting a baking business and our anti-trust friends will say that these men have made a "restrictive" agreement in restraint of trade and in violation of law, and they will weep for the poor people who cannot get bread.

The rather obvious truth about the license, however, is that it lays no restrictions whatever upon Waters. On the contrary, the license has *removed* a restriction on Water's activities which existed before the license. Before, he could not use Baker's invention for *any* purpose. After, he *could* use the invention in washers. Note that Waters has not agreed to stay out of the baking business or any other business nor has he been asked to. The license says nothing about it. The thing that keeps Waters from using Baker's invention in the baking business is the patent issued by the Government itself. *Before* the license it was the patent which prevented this. *After* the license it is still the patent. Baker has simply not removed the bar of the patent so far as the baking business is concerned.

And the license as above described is *solely* a removal of a restriction. Every patent license is, by its nature, a removal of a previously existing restriction. It is also true nevertheless that business agreements containing licenses, whether limited or not, have also sometimes contained added provisions which were in violation of the law. For instance, if—in our example—Mr. Baker had required Mr. Waters to agree to stay out of the baking business, that provision would almost surely have been held to be a violation of the anti-trust laws. If he had required Mr. Waters to pass some counterfeit money, there would be a violation of the criminal law, etc. Such unlawful provisions, however, have no essential relation to the patent license. The fact that they are sometimes included would be no reason for outlawing licenses, whether broad or limited.

The legality of a patent license may be tested in this way: If, after the license, the licensees's actions are not limited in any way in which they were not limited before the license, then the license is lawful. If some new limitation is imposed, then the new limitation is not justified by the patent law and is to be judged by the general law applicable.

Not only is a limited license—in and of itself—the freeing of a restriction on trade, rather than the imposing of a restriction, but it is an arrangement so beneficial to all concerned, including the public, that it is important there be no ban on such licenses.

In our example above, Mr. Baker was benefited because his patent still helped him to compete in his baking business, and in addition, he got a royalty from it. Mr. Waters was benefited because his washing machines were better—or cheaper to make, perhaps. And the public was benefited because it got better—or cheaper—washing machines.

If limited licenses were outlawed, Mr. Baker would not have granted any license at all, because if he did, it would have meant a license including use of his invention in the baking business. He would have been justified in saying, "If Mr. Waters wants to

compete with me in baking, let him think up his own improvements and spend *his* money to pertect and develop them."

WHY NOT "COMPULSORY LICENSING"?

Compulsory licensing, as applied to patents, means that the patent owner must license others to practice the invention upon payment of royalties—the amount of royalty to be set by some designated officer, unless agreed upon.

The suggestion that this be put into our patent laws has come oftener than any other proposal for emasculating them.

The frequent recurrence of this proposal may probably be accounted for by two facts. First, there is the persistent myth that valuable patented inventions on needed things are suppressed for commercial reasons—the compulsory licensing being expected to correct this; and second, there is the fact that most foreign countries have such a provision in their laws—from which it is reasoned we should have it also.

What has already been said under the heading of "The Magic of the Exclusive Right" shows why changing the right to exclude into a mere right to collect royalties would be destructive of our wonderfully effective patent laws. That part of the comment comparing the results in our country with the results in foreign countries which have compulsory licensing hardly suggests that we should copy them.

As to the idea that patents are used to suppress inventions valuable to the public, there is simply no truth in it. Yet it is doubtful if gossip to this effect will ever cease. It makes such a good "conversation piece." You cannot go around in public long until someone will ask you if you have heard about the patented carburetor that will enable a car to go up to 100 miles on a gallon of gas and, with some show of virtue and disgust, he will confide to you that the patent was bought up by the oil companies and shelved to save the market for gasoline from ruin—and there is no question about it because he got it straight from his sister-in-law who knows a man in one of the oil companies who actually saw one of the things! Or it may be a battery that will last 10 years, or a new treatment for leather that will make it last three times as long, etc. Such stories have been going around for more than half a century to the writer's personal knowledge, and, not one of them has ever been proved. Indeed, time and circumstances often disprove them. A patent runs for but 17 years, and the carburetor story has been bandied about for at least twice that long. Also, it must be remembered that as to every patent issued the Government has by law the right to use the invention (subject to just compensation) so that if any of these miracle-invention patents existed, we would soon know of it through use by the Government for war purposes or otherwise.

Witnesses before Congressional committees and before the Temporary National Economic Committee have again and again been questioned about suppressed inventions and through it all no single authenticated case of suppression has ever come to light. Thomas Edison told the Oldfield Committee in 1912 that he did not know of a single case. Before the TNEC, Mr. Baekeland, a prominent inventor and businessman was asked, "Do you know of any patent that is being suppressed?" and he answered, "No, I don't," and went on to relate that Mr. Parsons, Secretary of the American Chemical Society, circularized its

membership (running into the thousands) asking them to submit to him cases of suppressed patents, and that he didn't get a single example. Before the same Committee, Mr. Carlton of the Automotive Parts Industry testified that he knew of no case where a patented invention was suppressed to prevent its use, and was sure there was no such thing in his industry.

It must be remembered that nonuse of a patented invention is no evidence of suppression. Only a minority of the investments covered by patents are good enough to compete with other known things and so get into use. Some become obsolete because of later improvements even before they can be put in production—which often takes 5 or 6 years and sometimes much longer. Some are ahead of their time and must await collateral developments before they can be put to use.

The compulsory licensing proposal is usually aimed at a supposed abuse by big corporations. Not only are the particular abuses aimed at non-existent, but the big corporations could get along pretty well, relatively speaking, even under compulsory licensing. They are less dependent upon their patents than are the small companies. It is the individuals, the small companies and the public who would suffer most. This was brought out strikingly by the hearings on the McFarland compulsory licensing bill in 1938. No representative of a big company appeared to testify either for or against the bill, but the representatives of scores of small businesses crowded in to protest. They testified that their patents were all that enabled them to compete against the big fellows and many said flatly that they would fold up if the bill went through. The public would suffer not only because of the demise of small companies but because the American system of patents would then become little better than those of foreign countries.

Besides all other objections, there is the constitutional difficulty. The Constitution gives Congress power to promote the useful arts in only one way: namely, by securing to inventors the exclusive right to their respective inventions (supra p. 2). With compulsory licensing the right to exclude disappears, and we find instead the right to levy a tribute on the business of other users of the inventions. There is no authority in the Constitution for that as a means of promoting the useful arts.

Every time the compulsory licensing proposal has come before Congress, it has been rejected either in committee or on the floor.

In 1935, the Science Advisory Board's Committee made a study of the patent system for the Secretary of Commerce and recommended against putting a compulsory licensing provision into our law.

On both reason and authority, then, we must conclude that the compulsory licensing idea is a thoroughly bad one.

LET US GET THE MOST OUT OF OUR PATENT LAW

We have had our patent law for so long and have enjoyed its remarkable results so consistently that we are apt to take it for granted—to assume that, unless the law is repealed, we are sure to continue to receive the same benefits as in the past. It is well therefore that we should take note of various things that might reduce or destroy these benefits.

Government Ownership

It is said that the Government now holds more patents than are held by

any other single owner. More are being added to the Government list each year. There are some who say that the Government cannot, as a matter of law, own a patent. Without trying to decide that, we can at least say that, if this is indeed a government of the people, by the people, and for the people, the taking of a patent by government presents the curious spectacle of government granting to itself the right to exclude itself—the people—from using an invention.

In actual practice the Government does not sue citizens for infringement of patents standing in its name. It makes a somewhat pathetic attempt to get citizens to take free licenses under the patents and those administering the patents seem aggrieved that the citizenry shows little or no interest in the patents.

To the extent that this block of Government-held patents covers any industry it reduces the urge to improvement of that industry because the exclusive right has disappeared as to all the inventions of such patents. Also, for the same reason, the protection needed for the pioneering of new things has disappeared as respects Government-held inventions. To that extent, then, the Government-held patents are a nullificationof the patent system, and if all patents were government owned, the incentives of the system and all its other advantages would be at an end.

By ending its dealing in patents and by disposing of its present holdings for what they would bring on the market, the Government would do much "to promote the progress of the useful arts" and in doing so would save the taxpayer money.

Administering the Patent System

Our history shows pretty clearly that the kind of patent we give an inventor in this country provides just about the right amount of incentive to promote the useful arts. But such a patent, however perfectly fitted to the purpose, would fail to attain its end if the delays and difficulties of getting the patent were increased to the point where invention was discouraged at the very threshold, or if the quality of the patent were reduced to the point where there was no real presumption of its validity, or if the cost, delay and uncertainties of enforcing the patent right were so great as to render the grant worthless.

In short, however fundamentally sound our patent system may be, it is not self-operating. It takes a lot of machinery to put it into effect, and the benefits of the system could be lost through a breakdown in the machinery. It will pay us to take care of it.

Some years ago an inventor, having filed his application for patent in the Patent Office, had to wait two years, more or less, to get a first action on it. This was partly due to the effect of the war. It is somewhat better now but the delay is still much too long. Such waiting is a heavy reduction in incentive. Patent Office actions should be available within a month or so at most.

When the Patent Office examiners are behind with their work, they are constantly under pressure to get the cases acted upon. That is a poor atmosphere in which to obtain good examinations. The work is of a technical and quasi-judicial character. More thorough examinations and more accurate judgments on patentability would result if this rush-pressure were relieved. This would mean that the presumption of validity of the patents issued would become stronger. We would have less intentional infringement, fewer patent suits and fewer patents knocked out in court proceedings.

The trouble, of course, is that the Patent Office is understaffed. The cure is obvious—more men; and men of the highest grade. That is a tough prescription, of course, at a time when some real governmental economy has become imperative. But for many decades the Patent Office more than paid its way through the fees collected from inventors; and in the earlier years of this century had a large balance to its credit. In recent years the fees (though increased) have not wholly covered all costs. However, it should be noted that it is not only the inventor, but the public also that benefits from the patent system. The inventor should not be expected to bear the entire cost. If the public bore the entire cost (as with many Government bureaus) the public benefit would still amply justify it.

Judicial Difficulties

The cost and uncertainties of patent litigation can also reduce the incentive which our patent system holds out.

All litigation, of course, has an element of uncertainty. It is the duty of courts to hold patents invalid if they prove to have been mistakenly issued, but patent litigation could become little more than a gamble against loaded dice if our courts were largely manned by judges whose economic philosophy was collectivist. Such philosophy, deploring as it does all private property, would not be likely to look with judicial detachment upon the rights of a patentee, however good his patent. A judiciary loyal to the principles of our private enterprise incentive economy is therefore basic to a normal operation of our patent system.

The procedures of litigation have been improved and so, to some extent, made less costly in the last twenty years. Perhaps further ways to simplify, to speed up and to lighten costs can be devised. At least, fewer patent suits would be found necessary if patents were pretty generally found to be valid when sued upon, so that improving the job done by the Patent Office as above suggested would minimize the burdens of litigation. Impairment of the patent incentive by litigation troubles, to the extent it exists, occurs chiefly in the trial courts which account for all but a small fraction of the expense and delay of litigating patents, and primarily it is in those courts that improvement must be sought.

Our patent system has proved itself much too valuable to be lost by neglect of the things needful to make it work. In the words of the National Patent Planning Commission:—

> The American people and their government should recognize the fundamental rightness and fairness of protecting the creations of its inventors by the patent grant. The basic principles of the present system should be preserved. The system has contributed to the growth and greatness of our nation . . .

It is well worthwhile for those of us who understand the value of our patent system to tell others about it and to do whatever we can to build up a public support that will assure its preservation.

SUMMARY

A patent is a payment for the service rendered to the public in making and disclosing an invention, and is designed to enable the patentee to make a profit for himself if he can while the patent lasts.

It is the fact that patents are offered and granted that "promotes the

progress of useful arts;" not something that the patentee is required to do with a patent after he gets it. (The patent does serve as an inducement to market the invention during the patent's life, but that is not part of the contract.)

A patent under our system carries the unconditional right to exclude all others. Patents in other major countries do not—the right being conditional and also subject to periodic assessments, all of which weakens the inducement. Our citizens, under our system, out-invent those of other leading countries under their respective systems by better than two to one.

The flood of inventions in this country and the fact that we have far outstripped the world in the development of the useful arts indicate that our patent system holds out both the right kind and the right amount of inducement to devise new things.

The unconditional right to exclude which we give not only induces the making and disclosing of inventions but:

it invites and protects the risk capital necessary to get new things into commercial use;

it promotes competition in the making of improvements by others in the same line of business;

it stimulates the patentee to commercialize the invention whenever possible, because that is the only way to collect the reward;

it requires no considerable draft on the taxpayers' money, and it automatically matches the reward to the value of the invention contributed.

Our patent laws do not become out of date, since they merely provide a means of paying for services rendered —a custom not likely to go out of date in the next few thousand years.

Our patent laws do not conflict with the anti-trust laws. Patents like any other private property can be made the subject of *dealings* that violate law. The cure is to stop the deal—not to destroy the property.

The granting of limited licenses for the practicing of a patented invention is within the patentee's right. Such a license imposes no restriction on trade not already imposed by the patent itself.

A compulsory licensing law would destroy the right to exclude and so violate the basic principle which has made our laws succeed where those of other countries have failed.

A patent does not cover something taken from the public to give to an individual but is, on the contrary, a means of getting something from an individuals to give to the public—something which did not exist before the individual invented it.

The public, in its own interest, should be alert to protect our American system of patents from attack, or deterioration due to poor administratin and; should be generous in support of an institution that pays such great dividends.

PRESENT AND FUTURE DEVELOPMENT IN NAVAL ELECTRICAL EQUIPMENT

CAPTAIN ARTHUR C. SMITH, USN

THE AUTHOR

was born September 6, 1911, at Somerville, Mass. He graduated from the U.S. Naval Academy in June 1934, from the Submarine School in June 1937, and from the Post Graduate Course in Design Engineering, USNA, 1943. In 1946 he took the Advanced Management Course at the Harvard Graduate School of Business Administration. He has served in all departments on cruisers, as a Naval Aviation Gunnery Observer and as Commanding Officer of submarines. He was designated for Engineering Duty only in 1946 and since has served as Deputy Head Electrical Branch in the Bureau of Ships, as Design Superintendent at the Portsmouth Naval Shipyard, and is now Head of the Electrical Branch in the Bureau of Ships.

LOAD GROWTH, COMPLEXITY, AND THEIR INHERENT PROBLEMS

A few years before World War II, great publicity was given to an aircraft carrier which supplied the City of Tacoma with electric power using the electric ship propulsion plant. This carrier had 4500 KW of installed ship's service electric power capacity in addition to that propulsion power supplied to the city—a marvel at that time. Fleet destroyers had 580 KW installed. Today a new carrier will have about 13,200 KW; a destroyer 2,200 KW! What has brought this about and what does it mean to designers and operators? Does the future indicate a continuing trend and what is on the horizon for new electrical equipment? This article attempts to answer these questions and to evaluate what may be necessary in the future for the better understanding of both designers and operators.

Taking a carrier as an example, the increase in personnel since the SARATOGA Class has been 30%; the in-

crease of KW 193%. KW has increased from 1.9 per man to 3.4 per man. By comparison, the population growth in the United States for the same period has been approximately 16.4% while the installed KW in utility stations has increased from about 0.425 to 0.487 per capita. The basic reason for this growth aboard carriers has been the addition of new aircraft and ship's equipment to increase the fighting efficiency of the ship. For example, the shift to accommodate jet aircraft has meant an addition of 17 motor generator sets for jet starting and electronic servicing, and the addition of 675 KW for increased elevator capacity. New weapons, new electronics, and new damage control measures increase the electric power required. On other ships the increased requirements are even more drastic—minesweepers, for example, have increased their installed power by 600% because of advanced techniques in mining and countermining.

There are many problems connected with such phenomenal growth. Sheer bulk is the first obvious factor — if the number of pounds of electric plant per KW were allowed to remain constant, this phenomenal growth could only be accomplished by displacing military equipment or increasing the size of ships. The same applies to volumetric considerations. Two illustrations will show that concrete reductions in weight have been made; space has correspondingly decreased. A standard ship's service 600 KW turbogenerator set, including condenser, installed in 1942 on the CL55 Class weighed 28,500 pounds, or 47.5 pounds per KW; for the DL type ship the set is now maximum rated at 750 KW; its weight including condenser, is 21,540 pounds or 28.8 KW/pound. On minesweepers, where every pound counts, the pounds/KW of a diesel generating set has decreased from 59 pounds/KW to 44.5 pounds/KW. How has this been accomplished? First, by increasing rotating speeds; secondly, by the use of new materials; and thirdly, by the use of more precise engineering and better regulators which require less inherent regulation in the sets and, consequently, less magnetic iron in their construction.

The overall increase in power connected to a single system has made circuit protection against overloads and short circuits more important and difficult. For example, circuit breaker capacities to interrupt short circuits have gone from 75,000 amperes to 100,000 amperes in the larger sizes. Fuses have had to be developed so that they are rated, for special applications, to interrupt a short circuit current of 68,000 amperes in the 30 ampere size whereas a standard 30 ampere fuse is only rated to interrupt 1500 amperes at 450 volts. The complexity of the systems and the need for alternate sources of power in damage control has increased the number of automatic buss transfer equipments from none on old carriers to 60 on new types and has also increased their complexity.

Outside of the power systems themselves a corresponding development has gone on which reflects back upon the electric plant. Everyone knows of the growth of electronic systems, and interior communications. Each of the military requirements for these new systems results not only in a demand for more total power, but also in a need for better voltage and frequency regulation from the power source. Such regulation could be obtained through local devices at the equipment itself. To do this, however, imposes a multiplicity of special devices, such as closely regulated small motor generator sets, the aggregate of which adds total weight, space and maintenance that would not be necessary if the same regulation were inherent in

the power supply. Provision of the desired characteristics in the power supply is not always feasible, but the general trend can be seen in the presently specified 2% band regulation in voltage for a submarine set of 75 KVA whereas ten years ago 4% for a 2 KVA set was the basic requirement. This has largely been possible through use of magnetic amplifier regulators which combine inherent shock resistance with better regulation at some expense in complexity and weight. Their problems to designers and operators will be discussed later.

This survey of the past and present shows that power requirements have gone up; systems have become more complex; regulation has had to become better—while shock resistance, ruggedness and reliability have continued to be a basic inherent demand of any new equipment. Let us examine some of the basic methods by which this progress has been maintained and the knowledge which operators must have to run and maintain equipment which uses such new techniques.

NEW MATERIALS AND TECHNIQUES

The ability of a motor or generator to deliver increased power with all other factors fixed depends largely on its ability to throw off the heat generated within itself in such a manner that its continuous running temperature does not injure the electrical properties of the materials of which it is built. Since metallic materials are not affected by temperatures within the present range of operating temperatures and the only other materials present are those used for insulation and bearing greases, it is apparent that new insulating materials which can withstand higher temperatures will enable a piece of rotating equipment to develop more power in the same size, if bearing greases and tolerances can also stand this temperature. Many new materials have been developed; the chief advances have been in silicone insulation for rotating equipment, and melamine for block insulation. Since these materials are now coming into wide-spread use in industry and the fleet, a few words on them should be of value. Silicone (Class H) is a manmade compound which in its present form as winding insulation on rotating equipment can withstand hot spot temperatures up to about 400° Fahrenheit, as well as being more moisture resistant to salt spray than the previous Class "B" types, which, by the way, will take only 266° Fahrenheit. This provides the designer with the opportunity to increase power output within the same space and weight. Since the operating temperatures are higher, special heat stabilized bearings and greases must be used. Rotating equipment is now being used which, although not designed to the very maximum hot spot temperatures, does utilize this advantage of silicones such that it runs considerably hotter than old types of equipment. All equipments have on their nameplates the class of insulation, and if "H" is specified, operators should expect them to run much hotter than temperatures which would previously indicate incipient failure. They should check the allowed temperatures before becoming unduly alarmed and remember that special bearings and greases must be used as replacements. It should also

be remembered that silicones have special, different, baking processes and repairs should not be made using conventional varnishes, tapes, or baking techniques. Silicones are slightly less resistant to abrasion than old types of insulation. Fig. 1 shows what has been done to motors using silicones. The same avenue of approach has been taken in reducing shipboard cable weight by 20% and 35% in volume from wartime standards. New materials and new manufacturing methods have cut down the size and weight. Operators should acquaint themselves with the new temperature limits and changes in acceptable insulation resistances before concluding that new type cables are overloaded or have too low a resistance value, since these may well be within the limits of new designs.

Although not as apparent to operators, new types of fixed insulation have replaced older types of paper and cotton based phenolics. These new types do not support combustion and require less space for the same insulating values under the dirt or moisture conditions found on shipboard. One should be careful in maintenance work to replace insulating spacers, bases, etc., with like types of insulation if the performance intended by the designer is to be maintained. Bills of material or plans will provide the correct specifications for insulating materials.

Another avenue of approach to cutting space and weight is to increase the rotating speed of electrical equipment. Fig. 2 shows the effect on weight when speed is increased for various types of ship's service motors. As speed is increased, the mechanical problems involved in electrical apparatus become more acute. Better bearings, with correct lubrication have to be used; balance of rotating parts becomes more important and items important to resisting centrifugal force, such as banding wire and commutator securing methods must be of proper design. For example: The main bearing in a 24,000 RPM 400 cycle turbo generator has a clearance of 0.0045 inches as opposed to 0.006 to 0.009 inches in an older type 1200 RPM 60 cycle genera-

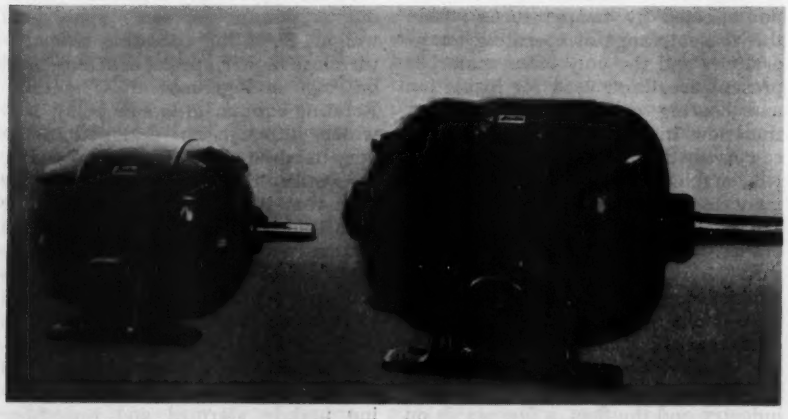


Figure 1. New 5 h.p. totally enclosed, non-ventilated Westinghouse motor (at left) protected with Silicone Insulation has same rating as much larger motor (at right) wound with Class "A" insulation. (Photo, Courtesy Westinghouse Electric Corp.)

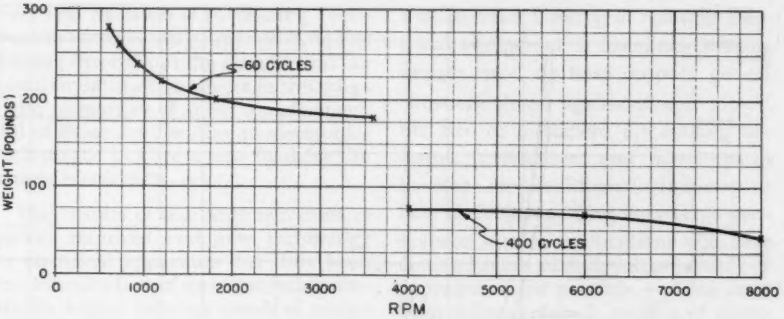


Figure 2

tor, and the permissible vibration of the higher speed machine is ½ mil., rather than 2 mils. in amplitude. These factors must be considered by maintenance personnel and operators in order that the machines may function properly, and instruction books consulted rather than relying on experience with slow speed machinery. In the field of circuit protection the same advances have been accomplished. Using new knowledge of the basic facts of arc interruption, industry has designed circuit breakers for submarines which were thought impossible ten years ago. No breakers were installed in propulsion circuits at that time because it was not possible to accommodate them in the cramped space available. A vigorous development program necessitated by the submarine's increased power resulted in circuit breakers which will interrupt 50,000 amperes at higher voltages than before. A comparable reduction has gone on in surface ship devices. A powerful new tool, the improved line of small air circuit breakers, has thus become available for protection and safety in electrical systems. As far as operators are concerned circuit breakers require very little maintenance. A knowledge of their application, the values of their interrupting capacity, and the effects of selective tripping on damage control should be known and appreciated.

Just coming into use are improved and new types of fuses; the generic name of a new type is the "silver sand fuse." They have new and interesting characteristics, chief of which is their speed of response, which enables interruption before currents can obtain dangerous values. Fig. 3 shows the time characteristics of a silver sand fuse and a standard fuse. Because of their ability to quickly cut off current, they will interrupt a circuit fault which, if allowed to continue, would go to 68,000 amperes. They are expensive and their characteristics are not needed in most naval applications —for special applications where very high short circuit currents can result from a fault, there is no substitute. Operationally a standard fuse should never be substituted for a silver sand fuse—the standard one will blow up under a heavy fault. In order to prevent an inadvertent mistake, fuse clips for this type are of a different size than for standard fuses.

One further general item finding its place in the fleet is the magnetic am-

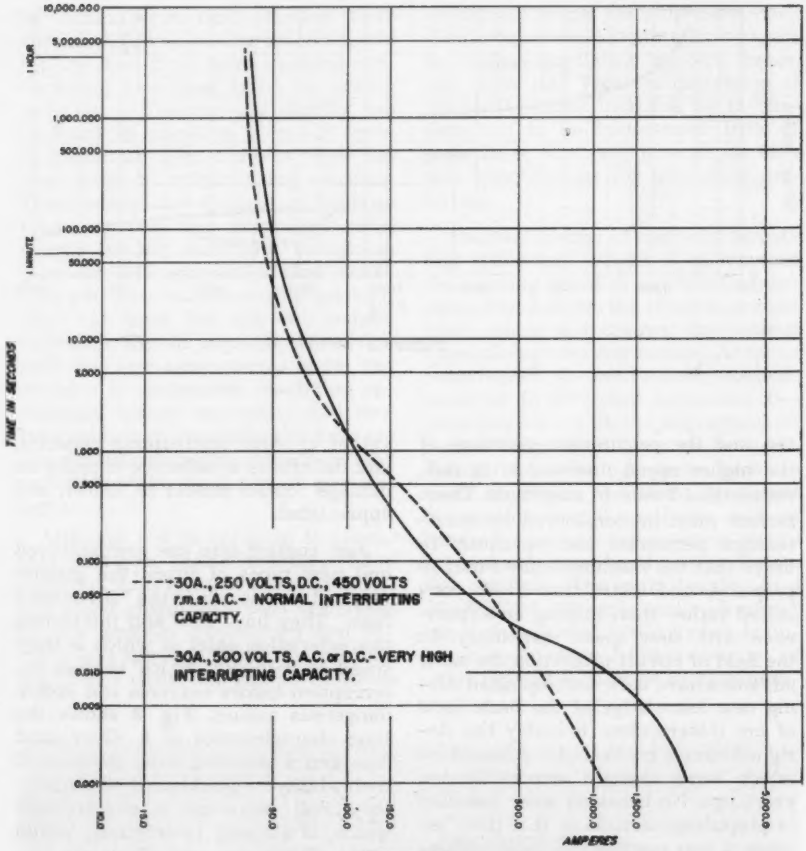


Figure 3

plifier. Its use has grown from practically zero in 1945 to countless applications now in service. Many technical articles on the subject have been written but there are a few important generalities for the operator and maintenance man to consider in using these devices. Magnetic amplifiers, amplistats and devices of similar name are essentially equipments which basically use special type transformers and rectifiers to control large amounts of power with small imput currents. As a system they use small resistors, inductors, and capacitors to obtain feedback or bias similar to electronic circuits. Their use is now so widespread that it behooves any users of modern shipboard electrical apparatus to understand their fundamentals and methods of adjustment. Of particular note is the maintenance problem of aging recti-

NEW HORIZONS

fiers and methods of measuring rectifier characteristics; proper phasing and biasing throughout the circuits and the peculiar saturation effects in the magnetic properties of their transformers. All of these are familiar to electronics technicians but are a new field for the power electrician.

The results of the large increases in power required and new technology in electrical apparatus has thus been the introduction of new insulating materials, higher rotating speeds of equipment, new types of protective equipment, and the introduction of many new regulating devices based on the magnetic amplifier. These are fundamental to the host of new devices which perform operating functions formerly unknown or done by other means.

Much progress has been made, but technology never stands still and the curve of new developments trends steeply upward. Already in the development stage are many items which will fill present needs of the fleet. Predictions are hazardous to make but are often productive in that they stimulate forward thinking. Let us try a few and see what may be on our ships in the next ten years.

Two items stand out in rotating equipment: motors which will run in air or fully submerged, and artificial methods of cooling. Submersible motors are needed for underwater ordnance, for actuating rudders, for submersible pumps, and for locations subject to flooding where continuity of service is paramount, such as bilge pumps. Various types of motors, oil filled, sealed, etc., are available now, but as yet there is no one fully submersible motor fit for all applications at all pressures. Such a motor can and will be built. Cooling of rotating electrical equipment is becoming a more urgent need as heat outputs go up, ships are closed against atomic attack, the size of inefficient air cooling becomes prohibitive, and more spaces become air-conditioned. Industry is now hydrogen cooling very large generators; marine applications will soon demand some such development. Four approaches are possible — none have been fully explored: cooling of shafts by fluorinated hydrocarbon refrigerants, gas cooling of interiors, water cooling by water vapor, and water jacketing.

Since cooling carries additional equipment weight, it will probably never be a final answer for small equipment; heat resistant materials must and will be developed. In this field new developments will have to be used. For bearings used beyond the heat-stabilized range of steel, some form of ceramic-metal compound will undoubtedly be used; the same avenue of approach is open for insulating materials above the 400 F range. In the static field, magnetic amplifiers will be simplified and standardized to the point where system output can be predicted by the assembly of standardized components, much as electronic devices can now be accurately designed from standardized components. Rectifiers will be vastly improved in power sizes, heat absorption capacity and aging characteristics. It should be possible to make greater use of non-linear conductive materials to make static inverters and rectifiers rather than rotating motor generator sets for conversion of large blocks of power from AC to DC or the reverse.

More use will certainly be made of magnetic clutches for all kinds of devices and their capacity will be extended to larger sizes.

CONCLUSION

The amount of electric power installed in naval ships has grown enormously in the past ten years; the equipment has decreased in unit weight and space while maintaining reliability under battle conditions. New developments will continue this trend and its use will become more widespread. The methods used to attain these goals and their operating implications should be known to Marine Engineers.

OPERATION OF A MARINE GAS TURBINE UNDER SEA CONDITIONS

ACKNOWLEDGEMENT

This is a condensed version, as published in the November 1953 issue of "The British Motor Ship," of a paper presented by John Lamb and R. M. Duggan, before The Institute of Marine Engineers in London on 13 October 1953. Included also are some notes on the discussion of this paper.

The 1,200 b.h.p. open cycle non-reversible British Thomson-Houston gas turbine set installed in the "Auris" is essentially experimental. It was designed for the express purpose of determining the problems likely to arise due to long continuous operation, varying conditions of atmosphere and sea and the burning of the heavier grades of liquid fuel. Before being installed in the ship the set underwent shop trials for 679 hours.

The "Auris" was originally propelled by four 1,105 b.h.p. at 375 r.p.m. Diesel engines driving A.C. alternators which supplied current to a synchronous motor directly connected to the ship's propeller shaft. This form of propulsion was adopted for two main reasons, the first being to obtain experience with the burning of high viscosity fuels in moderately high-speed Diesel engines, and secondly to permit installation of the turbine, then being constructed, at a later date. Also, it was desired to try out A.C. electrical current for all ship's services under sea conditions.

The removal of one of the Diesel engines made available a space which, though large enough to accommodate a gas turbine of the required power, placed certain restrictions on its design; in particular, the narrow width dictated the choice of an arrangement in which the h.p. turbine and compressor were mounted vertically above the l.p. turbine and alternator. Intercooling would not in any case have been adopted owing to the small mass flow, but the heat exchanger had to be limited in size. The Diesel engine, which was to be replaced by the gas turbine set, was provided with a completely independent fuel system which incorporated centrifugal purifying equipment of the type used so successfully on motorships burning high viscosity fuels. Such provision enabled firstly one Diesel engine and subsequenly the gas turbine to be operated on fuels of different characteristics, or fuels specially treated, while the remainder of the installation operated on normal grades.

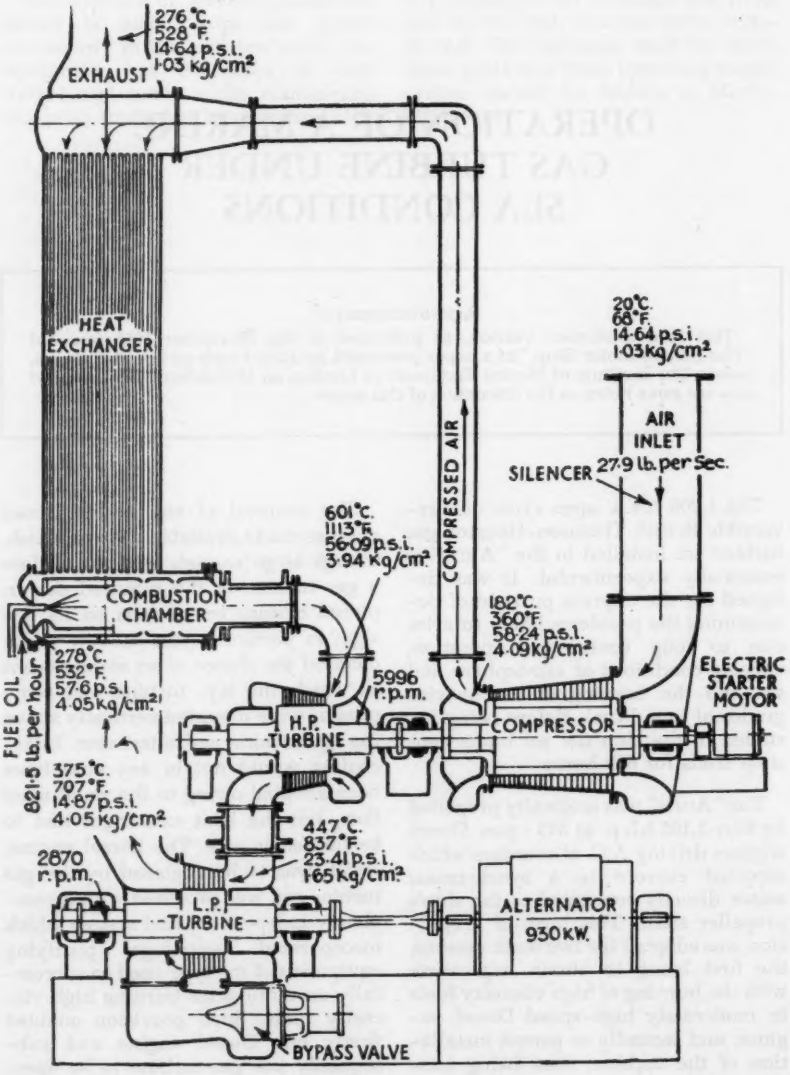


Figure 1

Diagrammatic layout of gas turbine showing air and gas paths, pressures and temperatures.

Figure 1 shows the air and gas paths through the components of the gas turbine and the designed pressures and temperatures. It also indicates approximately their relative positions in the ship. The preheated compressed air from the heat exchanger is led to the twin combustion chambers situated in the heat exchanger outlet drums. Only about a fifth of the air supplied by the compressor is needed for combustion of the fuel, which takes place in the refractory lined primary zone and which results in temperatures of 3,000° F. or more. The remaining four-fifths are led into the mixing zone in order to cool the gases to 1,200° F., the designed inlet temperature of the h.p. turbine. The h.p. turbine is coupled to the compressor, which absorbs the whole of its power output.

A short straight vertical duct leads the exhaust gas from the h.p. turbine to the l.p. turbine, which is coupled to the alternator and develops 1,200 b.h.p. or 860 kW. at the alternator terminals. From the l.p. turbine exhaust the gas flows upwards through the heat exchanger, as mentioned above, and thence to the atmosphere.

The set is designed to produce 1,200 b.h.p. at the l.p. turbine coupling when working in an ambient air temperature of 68° F. (20° C.), with a maximum h.p. turbine gas inlet temperature of 1,200° F. (650° C.) and a pressure of 47 p.s.i. gage. The designed speed of the h.p. turbine/compressor shaft is 5,750 r.p.m., and that of the l.p. turbine/alternator shaft 3,000 r.p.m.

The total weight of the set and its alternator is 55 tons (102.5 lb. per b.h.p.), the weight of the Diesel engine and alternator which it replaced being 43 tons. Included in the 55 tons is the 16-ton heat exchanger. Conclusions regarding weight ratio, however, should not be drawn from these figures because this turbine set was designed nearly eight years ago, and experience gained since indicates that, so far as power output is concerned, a considerable increase could be effected for the same weight.

Present-day standards would require an improved thermal efficiency and most methods of obtaining it involve an increase in weight. For example, air compression may be carried out in two stages, with an intercooler between the stages, and the effectiveness of the heat exchanger may be increased by enlarging its size and weight. Nevertheless, a long life turbine set of 5,000 b.h.p. could now be designed and built with a specific fuel consumption considerably lower than that of the "Auris" turbine, with no increase in the gas inlet temperature and yet with a total weight for turbine and alternator of only 74 lb. per b.h.p.

General Operation

The gas turbine set in the "Auris" went into service in October 1951, and it has operated under sea conditions normally encountered in all parts of the western hemisphere for two years, during which time the ship has covered more than 115,000 nautical miles. The set has operated without involuntary stops between ports, and on one voyage across the Atlantic in mid-winter it was by arrangement the sole propelling power, the turbine operating on fuel of 1,230 seconds Redwood I at 100° F. viscosity. A normal grade of boiler fuel with a viscosity not exceeding 1,500 seconds had been requested.

A feature which has impressed all who have seen the turbine operating is the total absence of vibration and mechanical noise. All that can be heard is a high-pitched whistle when the turbine is being worked up to full speed.

No major renewals have been necessary and the cleaning of the air compressor and heat exchanger has be-

come a routine operation which can be accomplished well within the time the ship is loading or discharging its 12,000 tons of bulk oil cargo.

During the shop trials and the two years service which followed, the gas turbine set has operated on load for 11,200 hours and consumed 3,468 tons of fuel. Of this period, 2,800 hours have been on fuels having a viscosity of between 1,200 and 1,500 seconds Redwod I at 100° F. During the remainder of the time, the set has run on normal marine Diesel grades. None of the fuel used has been ash free, the marine Diesel containing up to 0.06% of ash and the boiler fuel up to 0.09%. When all parts are working at their full efficiency, the average fuel consumption per b.h.p. is 0.75 lb. In the case of the 8,300 b.h.p. gas turbine set to be installed in the Anglo-Saxon 18,000-ton d.w. tanker now under construction, the thermal efficiency will be not less than 27% and the fuel consumption of the order of 0.53 per b.h.p. per hour. This set will operate exclusively on normal grades of boiler fuel.

When the set in the "Auris" was first put into service, the intention was to use Diesel fuel on the first round Atlantic voyage and then change over to more viscous fuel. At the end of the first voyage, however, slight corrosion of the first row of h.p. turbine blades was observed and new blades of greater heat- and corrosion-resisting properties were ordered. The set was then operated on boiler fuel, but when after a time it was learned that the new blades could not be delivered in under 18 months, the h.p. turbine inlet temperature was restricted to 1,100° F. and the set put back to work on marine Diesel fuel, although there was at that time no evidence to indicate that this grade was less detrimental in this respect. It was nevertheless assumed that it would be, and the changeover was made to avoid the possibility of the set being made temporarily unusable and experiments in other directions interrupted. The new blades are now being fitted and when the ship returns to service the set will be run on normal grades of boiler fuel.

A total of 172 gal. of lubricating oil has been consumed in two years and of this quantity 70 gal. were lost in the first few months due to joints leaking and trouble with the center pedestal bearing, as described later. The highest temperature attained by the white metal of the bearing in the hottest location was 150° F. with a sea temperature of 83° F.

Routine Inspection

Of the four rotating components of the set (alternator included) the h.p. turbine only was fully opened up for inspection during the two years' sea service. The deposit found on the l.p. turbine blades is a light brown dust in a quantity too small to have any adverse effect upon performance, while so far as is known at present no corrosion or erosion has taken place. The conclusion reached regarding this component is that it will operate for an indefinite period without attention on all fuels with a viscosity up to 1,500 seconds. More viscous fuels have not yet been used on the "Auris."

The h.p. turbine operates at the highest temperature and under the most severe conditions as regards impurities in the gases, and, during the 24 months' sea service, the upper half of the casing was lifted three times and on two of these occasions the rotor was also lifted.

The first occasion was at Curaçao at the end of the first voyage after 618 hours full power operation, the total including shop trials being 1,297 hours. The set had operated in a most satisfactory manner during the voyage, the reason for opening up so early being

to examine a welded part of the rotor shaft about which there was some apprehension. The weld in question dated from the time the set was built and the inspection proved the fears to be unfounded.

Prior to this inspection, marine Diesel fuel of 40 seconds Red. I at 100° F. viscosity was used. The fuel deposits on the first row of blades were not extensive, being about 10/1,000 in. thick, but were adhering firmly. The thickness of deposit on the subsequent rows became progressively less, there being no deposit on or after the fifth row. This component has seven rows of blades. The rotor was not lifted on this occasion, so that the stator blades in the top half of the casing only were visible. On the front face of these, some patches of hard corrosion scale were adhering, some of which had cracked and fallen off, while the back face was fairly evenly covered by a dark grey substance. A few patches of fuel deposit on the front face were observed but at no point was the corrosion scale or fuel deposit of measurable thickness. What is referred to as "scale" is the product of oxidation of the steel, whilst "deposit" is from the products of combustion and is mostly composed of ash.

As already mentioned, patches of corrosion were observed on the first row stator and rotor blades and it was decided to order four rows of blading of superior material, the first and second rows to be made of Nimonic 80A and the third and fourth rows of FCBT steel. The second inspection was carried out at Stockholm after a further 532 hours on load (total 1,829 hours), of which 135 hours were with the turbine burning high viscosity fuel of 1,338 second Redwood I at 100° F. The rotor was lifted on this occasion. Inspection showed some further deterioration in the first two rows of stator and rotor blades and an increased quantity of deposit. While the increased quantity of deposit was undoubtedly due to the use of heavier fuel, no definite opinion can be expressed as to whether the increased blade deterioration was due wholly or in part to the change of fuel. Also, it was noted for the first time that a portion of the blades represented by the 2/3 o'clock position of the first row of stator blades, when viewed from the exhaust end, were more affected than the blades in the remainder of the top half casing or any part of the lower half of the casing. Moreover, it was no longer possible to clean the blades to a smooth metal surface and the fuel deposits on the third row of blading were very hard and were found to be most tenacious.

The third inspection of the h.p. turbine was carried out at Curaçao after operating on fuel of 1,230 seconds viscosity for a period which included the voyage across the Atlantic when propulsion was by the gas turbine alone. The purpose of this inspection was to observe the effect of burning high viscosity fuel and to collect deposit and scale samples for analysis.

The trailing edge of the first row of stator blades showed distinct signs of wastage. There was also a noticeable difference between the front and back faces of the top half stator blades. When viewed from the low pressure end, the first six blades, counting clockwise from the left-hand side, were completely free from deposit excepting for a soft local accumulation at the root of each blade. The surfaces of these six blades were rough and dark grey in color.

On the blades to the right of the six referred to was a soft deposit which gradually became heavier as the right-hand side was approached. Underneath the deposit, which was easily removed, a hard white scale had formed, which could be removed but not easily. A feature noted on this occasion was that while the blades

reported as most severely corroded at the second (Stockholm) inspection were coated with hard white scale, they now appeared better in this respect than those on the left-hand side.

During the voyage preceding the third inspection, temperature traverses were made of the ducts leading the gases from the two combustion chambers to the h.p. turbine. These disclosed that a variation of 200° F. existed in each duct at a distance of 5.6 in. between the points of measurement. Also, although the temperature generally was 1,180° F., there existed an area where the temperature was 1,253° F.

From this it is evident that the stratification which occurs due to imperfect mixing in the combustion chamber persists round the inlet bend and scroll; consequently, some stator blades will be subjected to higher temperatures than others. When the temperature exceeds 1,157° F. (650° C.), laboratory work indicates that corrosion proceeds at an accelerated rate, probably due to certain constituents of the ash becoming molten. The exact point at which this occurs varies with the composition of the ash, but after 1,200° F. (650° C.) the corrosion rate is even more rapid.

It was also found in the earlier tests that when the lips on the shrouds became burnt, the temperature profile in the inlet ducts was affected, and this has subsequently been observed when any alterations or adjustments to the combustion equipment have been carried out.

Thus, the combustion changes carried out immediately before the second inspection can account for the most severely damaged areas of the first row stator blades moving from the 2/3 o'clock to the 10/11 o'clock position.

When opened up on this, the third occasion, a greater general accumulation of fuel deposits was found on the first few rows of blades. The first row stator blades were almost free of deposit when exposed, it having evidently reached such a thickness and weight that it readily became detached and fell off during the thermal contraction of the blades at the end of the run.

Two Forms of Corrosive Attack

The power output of the set is limited by a number of factors which operate under different conditions. The most important is the h.p. turbine inlet temperature, which is regulated by the fuel supplied to the burners. After the second inspection of the h.p. turbine, the maximum inlet temperature was, as already mentioned, restricted to 1,100° F. in an endeavor to prolong the life of the turbine blades pending their replacement.

The extent of corrosion of certain h.p. turbine blades has not yet been accurately measured as all original blades are still in use. When the most recent inspection was made corrosion was limited to the first four rows of stator and rotor blades. These blades, it might be pointed out, were made eight years ago of material which was the best then procurable. Since that time, superior material has become available and there is no doubt that considerably better results as regards resistance to corrosion will be obtained with the new blades.

The corrosion is attributed to certain constituents of the fuel ash formed on combustion. Two types of attack are recognized, one due to vanadium pentoxide (V_2O_5) and other vanadium-containing compounds, and the second due to sodium sulphate (Na_2SO_4). The mechanism of the attack by vanadium-bearing compounds appears to be one of accelerated oxidation, whereas that due to sodium sulphate is by inter-

granular penetration of the metal.

There is no doubt that the h.p. turbine blades are the most vulnerable to attack, especially when burning normal grades of boiler fuels, but experiences ashore and afloat are encouraging. Rules for the periodical survey of gas turbines have not yet been formulated, but from all points of view it seems desirable, even at this early stage of gas turbine development, that blade life should be not less than 20,000 hours, the equivalent to four years' service at 5,000 hours per year, and it is confidently expected that the materials chosen for the new blading in the "Auris" will fulfill this requirement.

After two years' sea experience with the first gas turbine propelling set to be installed in a merchant ship, the authors' views are as follows:—

(1) There is nothing in its operation which is beyond the capacity of the average ship's engineer. The absence of noise and vibration are considered to be desirable features.

(2) The gas turbine is not affected mechanically by any conditions likely to be encountered at sea in any part of the world.

(3) There is no reason why future gas turbine installations should not operate efficiently and continuously on the longest voyages.

(4) Apart from defects in materials and workmanship, the life of the major parts (h.p. turbine blades excepted) of a conservatively rated installation will not be less than the life of the ship.

(5) A life of not less than 10,000 hours may be confidently expected from h.p. turbine blades if made of the best material now procurable.

(6) While for equal power output the gas turbine has the advantage in weight and space occupied, and will in the not far distant future compare favorably with the Diesel engine in the matter of fuel economy, its main advantage is likely to be low maintenance cost.

(7) In contemplated gas turbine installations the emphasis should be on simplicity of construction until more experience has been obtained under arduous sea conditions.

(8) Satisfactory operation may be obtained with a gas inlet temperature in excess of 1,200° F., but with materials now available and for long continuous operation, a higher initial temperature is not at present considered advisable.

(9) While distilled fuels give the best results, the indications are that the difficulties at present encountered with the burning of residual fuels will be overcome.

(10) The leaning at the present time is towards electrical transmission, but the advantages of mechanical drive are attractive and these will no doubt be developed in due course.

NOTES ON THE DISCUSSION

SIR HAROLD ROXBEE COX opened the discussion and stated that he could not deny a certain enthusiasm for the gas turbine, but, like Mr. Lamb, he also had an affection for the Diesel engine, which must be with us for a very long time and which has many years of admirable service ahead.

At present, the efficiency of the Diesel engine is about twice that of the gas turbine, so that the gas turbine must still be considered as having a

long way to go. Referring to the advantages of the gas turbine from the maintenance and weight aspects, he cautioned that another weight to be considered is the weight of bunkers carried, and in that respect the gas turbine is at a disadvantage.

In considering high-temperature operation, it was pointed out that temperatures would be required probably twice those now being used. The "Auris" gas turbine is operating at a relatively low inlet temperature, and although some deposits remain to be disposed of, attack from vanadium and vanadium pentoxide has not been very potent. As temperatures are increased there is more danger. At present, because of the troubles caused by vanadium, the problem of burning residual fuel is much more difficult than that being experienced on the industrial side in burning coal and peat. If an efficiency of 45 per cent. has to be obtained, greater component efficiencies are required for the compressor and turbines, and, furthermore, it will be necessary to have compressors and compressor system with much higher compression ratios than at present. It is at this stage that the designer of marine and industrial gas turbines lags behind the aircraft industry, which has compressors of a higher ratio than those current designs for marine and industrial gas turbine applications.

Mr. B. E. G. Forsling, of the British Thomson-Houston Co., suggested that the gas turbine is mainly suitable for moderate powers of, at present, 3,000-8,000 s.h.p., a range suitable for the majority of ocean-going ships. Experience with the "Auris" gas turbine had indicated that, provided the initial temperature selected was not too high, neither ash deposition nor corrosion constituted such serious problems as research work seemed to indicate. The magnitude of the problems, he said, depended to some extent on the size of the gas turbine. A larger unit than that in the "Auris" and having larger blades and wider passages between them would obviously operate over a longer period before loss of material from corrosion and reduction of the blade passages due to deposition affected the performance to any appreciable extent.

This had been proved during the running of a 2,500-kW. gas turbine which was recently tested at the Rugby works of the B.T.H. The set was in operation for some 300 hours on residual fuel with a viscosity of 500 sec. Red. 1 at 100° F. and a total ash of 0.04%, so that, in fact, a light boiler oil was burned as it was received. During the test there was no falling off in efficiency, either of the turbine or of the set as a whole. The reduction of the effective flow area of the turbine was only about 1%, which was just outside the accuracy of the measurements. A gas turbine of adequate size, then, extrapolating the results, would be able to run for a considerable period, say 1,000 hours or more, before it became necessary to shut it down for cleaning. If the deposits broke off or could be removed without the need to open the turbine, marine service requirements would be met.

Mr. W. Kilchenmann, of Sulzer Bros., was interested to know how the proposed thermal efficiency of about 45% would be achieved. A maximum temperature of 1,000° C., or 1,835° F., is needed at the high-pressure turbine inlet, even assuming the best component efficiency and with a complicated plant arrangement.

For ship propulsion, preference would sooner be given to a somewhat simpler layout. In addition to this, no extremely optimistic assumptions are made for the component efficiency of the plant, so that a temperature of some 1,200° C., or 2,200° F., is necessary to obtain such high thermal efficiency. Attention must also be paid

to ensure that blade cooling arrangements do not cause excessive additional losses.

The burning of boiler fuel in gas turbines does not appear to have yet been solved, but he ventured that the ultimate solution should not be too difficult. Nevertheless, his firm had collected a lot of data on this subject and the conclusion has been reached that the problems to be overcome are greater than to be expected from the tests carried out on the "Auris." Particular care must be taken of fouling and corrosion as the extent of these rose with respect to the operating temperature and were also proportional to the concentration of the combustion gases. It was stated that his firm have made some promising tests with additives, the use of which, it was felt, is the safest solution to the problem of burning oil under increasingly difficult conditions of higher temperature and pressure.

Mr. I. G. Bowen, discussing the view held by many that ash deposits form an obstacle to gas turbine progress, referred to the findings on the experimental gas turbine at C. A. Parsons and Co., and summarized by Bowden, Draper and Rawling. They were, briefly:—with combustion conditions in which all the carbon was burned, the Parson gas turbine suffered a very high rate of ash deposition. If the combustion conditions were altered to produce a sufficient quantity of what were known as "stack solids," then the turbine was kept free of deposits. A second solution was found with the introduction of additives to the fuel which resulted in a reduction of deposition for periods of running up to 30 hours. The most promising of these was silica added to the fuel in a soluble form and this was suggested by Sulzer Bros., who had found a reduction in deposition with that element in both rig and engine tests.

Reference was made to a postcript in the paper wherein the authors described their recent experiences on heavy oil. With a normal residual fuel containing 0.07% ash, the "Auris" crossed the Atlantic with a reduction in turbine area of 5% in 500 hours. That corresponds to 10% power, allowing for change of ambient temperature.

It was then stated that the stage is set for full-scale trials on heavy oil and recently three separate tests had been carried out. A fuel of high ash content was chosen—12%—and the first run was on the existing build with no attempt to produce stack solids. The result was a rapid build-up of deposits and in 70 hours the turbine area was reduced by 21%. After shutting down, a good deal of this deposit fell off. The following test was one on which atomization was coarsened by reduction of the fuel temperatures in order to produce stack solids. The test ran 140 hours and the turbine area steadied after 100 hours to a value of 8% below that at the start-up.

The third test was the use of a silica-additive but with the assistance of increased stack solids. After some initial difficulty, a continuous run of 94 hours was achieved in which the turbine area was increased by 4%.

Mr. Lamb, in his brief reply to some of the more general points raised, said that a 45% efficiency was no doubt high but that it was better to aim high than low and results from only a limited number of years' work on the project encouraged his aims. Progress is more rapid than generally realized and it was mentioned that whereas the "Auris" has an efficiency of about 20%, the set now under construction for the Anglo-Saxon 18,000-ton tanker should attain 28%. Referring to the suggestion that aeronautical developments of the gas turbine had something to offer the marine field, he

said that his company wants a turbine to last not a month but for the life of the ship—for 25 years. He felt sure that good progress is being made towards that end. In the "Auris" no major part has been renewed, and although the whole turbine is to be opened up, no renewals are anticipated.

FREE ENTERPRISE WITHIN THE NAVY AN EVALUATION OF REPAIR SHIPS

CAPTAIN JOHN ADRIAN HACK, U.S. NAVY

THE AUTHOR
is a graduate of the U.S. Naval Academy in the Class of 1935. After varied service in destroyers and submarines he received post graduate instruction at Rensselaer Polytechnic Institute where he was awarded a degree of Bachelor of Management Engineering. Service as Executive Officer in USS SIERRA, as Commanding Officer USS EPPING FOREST, and in his present assignment on the Staff of Commander Cruisers and Destroyers Pacific Fleet, have allowed him to observe the many applications of Industrial Management principles in the Fleet. This is his third story concerning Captain O'Shaughnessy.

Captain Michael O'Shaughnessy like most of his contemporaries was a child of the Great Depression. His introduction into the Navy had been one in which the practice of economy was not accompanied by fanfare of propaganda. "Cost Consciousness," 'Better Management," "Greater Productivity" and the other catchy phrases of our day were unknown to him in those grim early thirties. Frugality had been such a routine matter that it had been the normal way of life. But the building of the sinews of defense, followed by the war years and the tensions of the early fifties had dimmed his memory of those days when he had scrimped and saved! Turning off unnecessary lights, screaming at the slightest steam leak, cajoling every man Jack to save water, O'Shaughnessy's memory was hazy on the details of how, as a young Engineer Officer, he had gone to fantastic lengths to save enough precious oil so his ship could steam to sea, fire the guns, and return to save once more for another day. He had almost forgotten the pauper's pence upon which the Navy had operated; how he had weighed every expenditure of the quarterly allotment as carefully as his wife now debated whether she should invest in a steak or a pair of shoes for the children. The years had dimmed his memory but they had left a deep mark in his character. He knew the value of a dollar!

Now he faced his greatest challenge! Not that every step of O'Shaughnessy's

career had not been a test. But this was a different kind. His Navy had been a series of ships and jobs in which he could personally combat any weed of waste as it appeared. Through lectures, example and simple administrative procedures it had not been too difficult to teach others the principles of economy. Manpower utilization, material conservation, and the importance of time in the scheme of things had been the subject of many talks through which he had influenced a parade of officers and men to strive for the best way to accomplish their mission. They imitated, in their Navy way, the philosophy on which America had grown great as she provided more things for more and more people. As Commanding Officer of the U.S.S. WHITE MOUNTAINS he had taught a repair ship to achieve a productivity comparable to a privately owned factory. In time every department had been imbued with those principles of Industrial Management which drove them to seek how to accomplish the most work at the least overall cost.† Later as Commanding Officer of the U.S.S. HERMITAGE he taught his crew to fight Communism in a daily restraint against spending. They had learned that every dollar not spent was another sword in their hands against a potential enemy.* But these achievements were minor and personal ones. Now he was assigned to a Staff and challenged to put his ideas into operation on a force-wide basis; to achieve in a chain of repair ships scattered over half the globe the results he had demonstrated were possible in one. How would he start? Where would he end?

The first few weeks of his new duty were akin to the legendary visit of Alice into Wonderland. Details flowed across his desk in an endless stream of letters, messages and instructions which threatened his sanity. As if to taunt him the President had issued an order to each Federal Department:

"It is imperative that you emphasize a critical review and maximum feasible reduction of expenditures in areas which have attracted the attention and concern of the Congress and of the public as possible sources of waste, inefficiencies, duplication, and excessive or non essential costs."

This order had been passed along by the Secretary of the Navy in words which could leave little room for doubt in anyone's mind:

"It is encumbent upon all persons in the military service to whom the administration of funds are entrusted to insure that such funds are judiciously, economically and efficiently expended. Commandants, commanders, commanding officers and officers in charge will insure that:

1. Operational and logistic requirements are based upon sound program planning.

2. Budget estimates and requests for funds include only essential requirements to accomplish this mission at the approved level of operations.

†See—"Management by Exception"—Journal of the American Society of Naval Engineers—November 1951—and "Captain O'Shaughnessy-Businessman in Blue"—Journal of the American Society of Naval Engineers — February 1953.

*See "It's Your Own Money You Are Spending"—Naval Institute Proceedings—November 1953.

3. All requests for funds are realistically priced.

4. Funds are administered in such a manner as to insure accomplishment of the programs or operations for which the funds were appropriated and allotted.

5. Funds not necessary for current operations are returned to the allotting source so that savings can be realized, or more urgent requirements can be financed.

6. All personnel are fully cognizant of the responsibilities attendant to the administration of appropriated moneys."

From his desk, reading through the mountains of paper, O'Shaughnessy had attempted to analyze the effectiveness of the Force's tenders in the light of these directives. He knew that wastes were present yet couldn't put his finger on them. Budgets for "Repairs to Other Vessels" funds were based upon last year's performance as a standard. Availabilities were granted to the destroyers in the traditional manner. He was convinced that all echelons were carefully screening work requests, even though he noticed that many jobs within the capability of force's afloat had to be accomplished during the Navy Yard periods. Oh, there was a tremendous effort to achieve economy. Every day a letter told of some minor saving achieved by a ship. These were important as a demonstration of the will to save, but they seemed to him to be only nibbles at the frosting. Somewhere a hidden but expensive cake remained. There was nothing about him which didn't follow the traditional Navy pattern, yet he couldn't answer some very important questions!

Rereading the Secretary's directive O'Shaughnessy sweated as he attempted to formulate in his mind the answers to the questions he knew full well would be asked by the Admiral tomorrow. "What planning for repair requirements has been made in this Force?" "Exactly how were the various budgets for repairs formulated and how did they match the logistic requirements?" "What controls were now in effect to insure that the moneys were in fact well spent toward the end that combat readiness was assured?" "How are we going to know when we may turn in unnecessary funds to the allotting source?" "In plain and simple language, O'Shaughnessy, how much work are my tenders doing, and what is the demand for work upon them?"

"I notice that we have spent a considerable amount of money at shore repair activities lately! Are our tenders, in fact, so overloaded that they couldn't have handled this work?"

O'Shaughnessy dreaded the inevitable interview for frankly he knew that his answers were going to be so much gobble de gook. The budget was based upon last year's expenditures, but how much should they have been? So far as he knew the tenders were assigned, in numbers, according to the old traditional concept that a tender was to take care of a squadron of destroyers. Everyone knew that such an organization was non existent outside of the submarine navy. The reputation of the tenders was based upon so many intangibles. True, there was a production index published, which compared the

man hours expended with the potential manpower in every repair department, (based upon the concept that every man could work eight hours a day). But there's a vast difference between the time spent in doing a job, and the amount of work done in that time. O'Shaughnessy wouldn't fall into that trap. He was too aware of the fact that employment which wastes time is a criminal waste of a vital resource. In fact his brief time in office had allowed him sufficient time to discover what some tenders were doing to bolster their index of production. Non productive workers, including vital supervisors, had been reduced in an effort to get more hours of work into the records. When there wasn't sufficient work to keep everyone busy there was a natural slowdown to keep the hours of work up to an acceptable standard. If only these ships were a chain of factories! O'Shaughnessy wished, for then the standards would be so clearly set by the public that he, as a manager, would either see them or be drowned in the red ink of losses. If only his tenders were in the free enterprise of private industry!

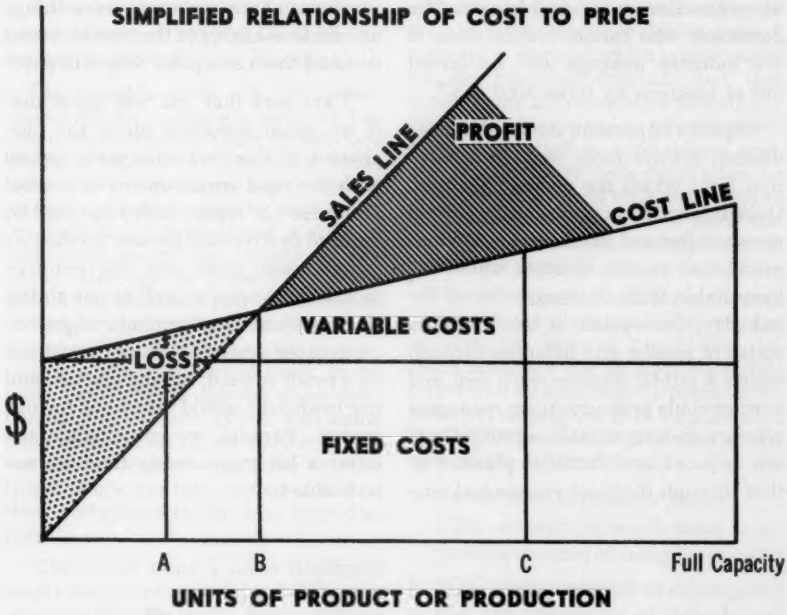
And with the wish came the germ of his solution! Not only to his immediate problem of answering the Admiral's questions but to the more important one of setting up a chain of efficiently run destroyer tenders.

He spent the entire night reviewing his textbooks on Industrial Management, and the files of correspondence which related to the administration of the repairs to the Force. It seemed reasonable to him that destroyer tenders were but floating mobile counterparts of the factories all over America. They sold repairs to destroyers on a job order basis just as the others sold to you and to me. That being so the principles of free enterprise *must* apply to them. Violation of the laws of good business would result in a loss. Poor management, low productivity, over expansion . . . any waste of time, manpower or materials must inevitably result in a loss of money and hamper realistic planning. Any or all would be a direct violation of the President's order!

By morning, Captain Michael O'Shaughnessy had found his solutions. In a conversation with the Admiral he initiated the action which placed the tenders of his force into the free enterprise system, and by doing so commenced to exert pressures upon the ships which the public places upon any businessman who attempts to operate a segment of industry.

"Admiral," he began, "you and I, and many before us, have been plagued with an inability to answer in concrete terms what have appeared to us to be legitimate and forthright questions. How many repair ships do I need for my force? In more useful terms, what should be the capacity of a tender to do work, and what should be the demand of a destroyer to have work done? How much should it cost to accomplish that work? With my forces scattered throughout the world how can I tell which of my tenders is doing a good job and which is not? What standard could I use which, if published, would not become an end to itself and produce artificialties which make the score the only goal? What we have been asking after reading the President's order was in fact "How can I introduce my tenders into competitive industry and thereby gain the same advantages for the service as have been gained by the managers and the public who follow our economic industrial system of free enterprise. How can a government activity avoid the pitfalls of a totalitarian economy when its operations do not demand an accounting, per se, of profit or loss to the general public consumer and the stockholder investor?"

Placing a chart upon the Admiral's table:

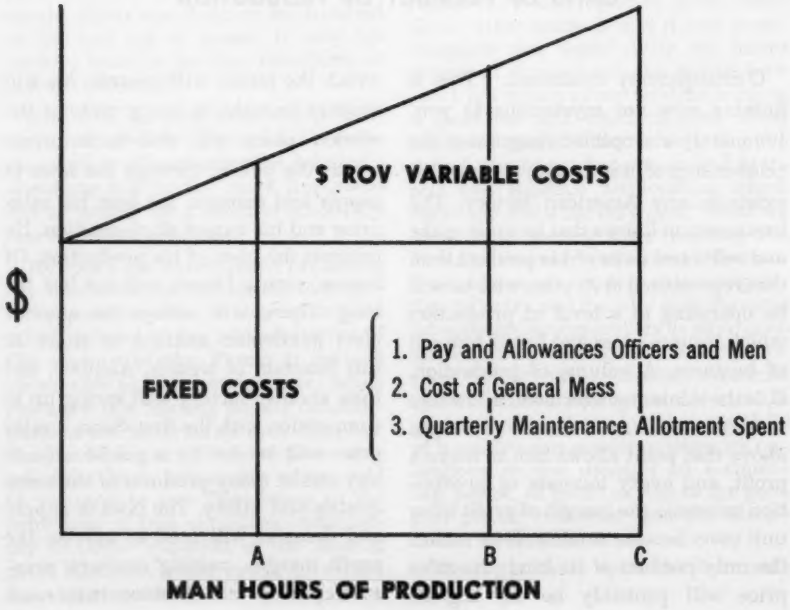


O'Shaughnessy continued: "This is nothing new nor mysterious to you! It's merely a simplified diagram of the relationship of cost to sales price which exists in any American factory. The businessman knows that he must make and sell more units of his product than that represented at A, otherwise he will be operating at a level of production which insures a loss and forces him out of business. A volume of production, B, is the minimum which will allow him to break even. An increase of output above that point allows him to make a profit, and every increase of production increases the margin of profit since unit costs become smaller. If he makes the only product of its kind, the sales price will probably be the highest which the public will tolerate. He will attempt to make as many units as the market place will absorb. In other words the public, through the laws of supply and demand, set both his sales price and his output of production. He controls the costs of his production. Of course, such a Utopia will not last for long. There will always be another alert gentleman anxious to share in this fountain of wealth. Another, and then another factory will spring up in competition with the first. Soon, a sales price will be set by a public able to buy one of many products of the same quality and utility. The laws of supply and demand will tend to narrow the profit margin, putting constant pressure upon the manufacturer to increase

his production or reduce his costs. The inefficient who cannot reduce costs to the industry average will be forced out of business by those who can."

"Equally important, the level of production always must seek to achieve that level which the demand justifies. Overproduction is punished by unsold merchandise and idle factories. Underproduction results in costs which are inequitable with the remainder of the industry. Our system is based upon a series of checks and balances through which a public imposes very real and very obvious pressures upon managers who are seeking to make a profit. Costs are reduced, and facilities planned so that through the most economical employment of our resources more things are made available to the numbers who demand them at a price they will pay."

"I am sure that you will agree that if we could somehow blend the mechanics of this free enterprise system with the rigid requirements of combat readiness our repair activities could be induced to strive for greater productivity at lesser costs, and our requirements for repairs as well as our ability to meet those requirements might become more apparent. There would not be a profit reward, but the efficient and the inefficient would stand out for our review. Perhaps we could guide the latter a bit more surely than we are now able to."



"Let's assume that a tender was a privately owned factory. Costs of operation might well look like this:"

The variable costs are the dollar values of the materials used in the repair of destroyers. These in fact constitute a measure of the work done, since similar repairs are being accomplished upon destroyers by each tender. Note that I have placed a scale of manhours across the bottom of the chart. Although at present we place our entire reliance upon manhours as a measure of production, it really measures the effort expended in producing a given amount of work. In no sense can it be considered to be synonomous with work, as you well know from observation of the output of the various tradesmen who come to your house. Some are lazy, some a credit to their companies in the zeal they display."

"The fixed costs I have displayed might well be considered to be the cost of accomplishing work. Some of them are necessary. Some are larger than we would expect to see in a civilian factory since our factory is mobile. But some of these costs might prove to be mere waste!"

"It seems logical to me that a repair ship should strive to achieve the maximum production at the least possible cost consistent with her combat readiness. The absence of a sales line on the chart does not imply that the same principles we discussed before do not apply, but merely that there is no public setting a price which is obvious to us, and which will allow us as managers to be warned that we are operating at a loss. Since there is no public to set the laws of supply and demand into motion, it is our responsibility to simulate the pressures of the man in the street. It is vital that we try to establish the level of production which the public would set for us in the free market place. In brief, our management aim must be to so establish our Repair Ship Industry that only that amount of capacity is planned which is warranted by the potential demand, and that through our administrative procedures we create an incentive to achieve maximum production at a minimum cost. The standards we seek must allow us to budget our needs with some degree of accuracy according to a plan, and thereby allow us to return funds as conditions change."

"I believe that the standards we seek will set themselves, and that we can simulate the laws of supply and demand so surely that an invisible public might well be applying the pressure we seek. Let us suppose that we published in competitive fashion, for each of our tenders the following ratios:

1. PRODUCTION EFFICIENCY INDEX

   (The amount of work done compared to the cost of doing that work.)

   $ ROV (*spent on repair of destroyers*)
   $ Pay and allowances of Officers and Men
   $ Cost of Operating the General Mess
   $ Expenditures of Quarterly Maintenance Allotment.

2. PRODUCTIVITY INDEX

   (The amount of work done compared to the effort expended in doing it.)

   $ ROV (*spent on repair of destroyers*)
   Man hours spent in production.

"In order to improve the ratios the Commanding Officer will have to do the same things which the factory manager seeks to do if he is to maintain a satisfactory margin of profit. He must either increase his production or decrease his costs. Any attempts to introduce artificialties will be useless for we are using accountable dollars, already recorded in inviolable records as the source of our principal index. A

glance at the chart will demonstrate why these facts are so."

"The Commanding Officer can increase his PRODUCTION EFFICIENCY INDEX only by:

"*1. Increasing his $ ROV.* This he may do:

(a) By increasing the productivity of each man through training programs, by better supervision, or by establishing some incentive system as a reward for work accomplished.

(b) By reorganization of his departments to the end that the minimum required by sound organization principles are employed in the non productive departments, and the maximum are employed in the Repair Department. Other departments might well assume productive work where the particular skills are needed in destroyer repairs.

(c) By adoption of sound methods of production analysis, scheduling and control to insure that time is not wasted and that work demanded is in fact scheduled up to the full limit of potential capacity."

"The index could also be increased by wasting materials but we could easily spot such a procedure by investigation of any marked increase of $ROV which cannot be explained from the above steps."

"It is important to note, Admiral, that *we* can affect this index also, by any restrictive administrative procedure which blocks a constant flow of work from destroyer to tender shop. Our present system of assigning an availability for every type of repair, and demanding that work requests are screened by every echelon, makes it impossible for a ship to get ship to shop repairs accomplished as they are needed. Days are consumed in screening work requests, and every ship would have to ask for an availability almost every day. The obvious answer is to grant automatic availability for all ship-shop work and allow each destroyer to deal directly with the tender. A constant work demand will insure that maximum productivity is achieved, and at the same time serve to fix, for our information, the supply and demand of destroyer repairs."

"*2. By reducing the fixed costs.* This he may do:

(a) By reducing the pay and allowances through a systematic job analysis aimed at reducing the complement to the lowest point consistent with sound organization principles. This is one of the objectives of the current Habitability studies and certainly is in harmony with the hue and cry for manpower conservation.

(b) By elimination of waste in the General Mess.

(c) By emphasis on the Material Conservation program, reductions in the Quarterly Allotment expenditures might be possible."

"The value of these indices," O'Shaughnessy continued, "lies chiefly in the achievement they tend to stimulate. By their publication they would allow higher authority to be aware of those units which are inefficient. In short, Admiral, you could tell who is, and who is not, pulling on the oars."

O'Shaughnessy handed the Admiral two sheets of paper in way of emphasis. "Here are the records of our ships for the past few months":

COMPETITIVE STANDING OF DESTROYER TENDERS
(Cumulative since 1 July)

Tender	Standing	Production Efficiency	Productivity
A	1	.065	.26/mh
B	2	.050	.20/mh
C	3	.040	.19/mh
D	4	.025	.15/mh
E	5	.015	.14/mh
F	6	.014	.11/mh

NOTE: These figures are ficticious. Actual figures are available upon request.

TENDER PERFORMANCE DATA
(Month of October)

	A	B	C	D	E	F
Average Number of Personnel						
(a) Officers						
(b) Men						
Average Repair Dept. Personnel						
(a) Officers						
(b) Men						
Production Man Hours						
Nature of Work Load						
(a) Routine						
(b) Unusual Damage						
Number of ships worked on						
Costs:						
(a) ROV						
(b) Pay and Allowances						
(c) General Mess						
(d) Quarterly Allotment Expenditures						

(Actual figures are not listed here since they might disclose classified information in an indirect manner. They are available upon request.)

"It is obvious Admiral that tender "A" is far and away the best tender in the force. It represents a challenge for the others to equal. You will notice that ship "A" and ship "F" have expended the same number of man hours. For the same effort ship "A" produced almost four times as much work. One of the reasons why this can be so is the sound production planning, scheduling and control system which it employs. Another is the incentive given to men to work harder, through definite rewards for work well done. Her general mess was operated at less cost even though she has almost two hundred more men aboard. I have seen both messes, and can only conclude that the

difference must lie in the value of the garbage. Ship "A" feeds as well as, if not better than ship "F".

"One last point is of interest. The data tends to show the supply and demand for tender repairs. If we continue to collect this information for a period of a year, we will be able to demonstrate the annual requirements of a definite number of destroyers for repairs, as well as the capacity of an average tender to accomplish them, in terms of the same units, material dollars. For budget planning, several steps are obvious. The tables will give us information from which we may calculate:

(a) $ ROV required during a given time to support a specified number of destroyers.

(b) $ ROV required to support the activity of a given number of Repair personnel.

(c) $ ROV necessary to finance the various types of repairs.

For each of these, high-low budget data is available for us to use."

"The guesswork is eliminated in answering the budget questions highlighted by the President's and the Secretary's orders. These can be our tools of management, which once set into operation, will make our Tenders a true counterpart of private industry, and place upon them the same influences which the public exerts upon privately owned factories. By operating according to the principles of our chosen economic system, we can drive one more wedge into the argument of those who claim that the American way must step aside for a new and totalitarian theory."

Yes Captain O'Shaughnessy your ideas will work! In fact your systems were instrumental in the return of almost two million dollars of repair funds which were not necessary once your Repair Activities started to absorb the production you knew they could. In the Navy, as in all of America, maximum productivity has always come from competitive enterprise. American talents have produced a standard of living and a capacity for production the likes of which the world has never seen. Our system of free economy is on trial before the world. You, and your fellow officers, have a responsibility to prove that in your profession too, the American way of life need bow to none. In doing so, the Navy will be a better place in which to serve. America will be a safer place in which to live.

SALVAGE OF THE M. H. DE YOUNG

COMMANDER ARTHUR C. BUSHEY, U.S. NAVY

THE AUTHOR

Commander Bushey is a registered architect and registered professional engineer in the State of Maryland. Since his retirement in May 1953, he has been engaged as a consulting engineer in Baltimore. During this period he has also been vitally concerned with research and development of laminated plastics, a project he fostered while stationed in Contract Design (Hull), Bureau of Ships from 1946 to 1952.

During his last year of active duty, he served as the Senior Assistant Supervisor of Shipbuilding and Naval Inspector of Ordnance and Assistant Industrial Manager, Baltimore. During World War II he was attached to the South Pacific Command, later serving as officer in charge of shipbuilding and ship repairs in New Zealand and commanding officer of the U.S. forces in Auckland.

The late King of England invested him as an Honorary Officer of the Military Division of the Most Excellent Order of the British Empire. He was also made an Honorary Commander in H.M. New Zealand Coast Guard and for his service in the South Pacific he was decorated with the Bronze Star Medal.

The S.S. *M. H. DeYoung,* a new Liberty, was on her maiden voyage during the summer of 1943 from San Francisco to Australia, with a precious cargo of heavy machinery. Unescorted, near the equator, on a beautiful moonlight night she presented a welcome target to a surfaced Japanese submarine lying in the shadow of a small island. The lookout saw the torpedo as it sped toward his ship. The Master threw the switch in front of the helmsman for General Quarters. The Armed Guard started shooting in the general direction of the torpedo. The torpedo struck amidships on the starboard side (Figure 1). Later enough fragments of the torpedo with sufficient markings were found for the experts at Pearl to identify the size and MK no. A bronze plug was also found among the fragments which bore the foundry stamp of one of our mid-western companies —part of the scrap metal purchased many years before.

The engineer and fireroom watch were lost in the water which flooded the combined engine and boiler room. (Figure 2.) Fuel oil from the tanks at the aft end of this space covered the water. A Navy lieutenant, a Reserve, was killed outright while walking down the Upper Deck passageway. The door to the engine room was

Figure 1. The torpedoed S.S. M. H. De Young

Figure 2. Looking down into the engine room of the S.S. M. H. De Young

blown off its hinges and sailed at him. The chief engineer was sitting up in his bunk. The explosion carried the deck and the rest of his bunk away, but he escaped unhurt. The wooden sides of the temporary additions to the superstructure for housing military passengers were blown off in almost complete units, but the occupants of the berths escaped injury.

Many of the merchant crew took to the life boats. It was only after continued assurance by the Master that they returned.

It was decided by high authority that this cargo must be saved and I was so instructed. It was rather fortunate that the cargo contained all material which might be necessary for a salvage operation. The problem became one of getting available personnel to do necessary work. I was advised by higher authority to weld several hatch beams across the hole made by the torpedo. However, I was convinced from examination of the ship that the gap and cracks extended to the garboard strake, but that the keel, vertical keel, one entire side, both sheer strakes and both stringer plates were intact, so I did nothing to strengthen the ship. I allowed for a bad garboard strake in my estimate of the situation. Docking, months later, at Espirito Santo revealed a crack in the garboard strake.

Chief concern at first was the possibility of faulty bulkheads fore and aft of the engine room (Figure 3). Soundings were taken twice daily and recorded. Sight battens were established to ascertain by readings each morning and afternoon if any major longitudinal deflection developed. These soundings indicated progressive flooding of No. 5 hold at approximately the same rate as in hold No. 4. Flooding of hold No. 4 could be attributed to a cracked bulkhead, but I could not believe that the explosion had affected the bulkheads further aft. From a study of all of the drawings available, only one cause appeared and that was syphoning through the piping connected to the sounding tubes. Part of this piping was in the shaft alley. As soon as possible these pipes were cut and plugged.

The first task was to pump out the shaft alley. To do this a passage had to be forced through No. 5 hold and a hole cut in the ships side in order to get at and use a pump without having too great a suction or too much pumping head.

This operation was necessary from two other standpoints. The first was to wedge and caulk the engineroom-shaft alley door which was not tight and permitted water to enter the shaft alley in an increasing amount daily—about 2/3 of our 24-hour pumping capacity. As a matter of fact this work was accomplished with about 3 ft. depth of water at the aft end of the shaft alley, a dangerous task. The other obvious reason was to improve the trim so that cargo could be transferred to a ship alongside.

When the *DeYoung* left the West Coast on July 29, 1943, her drafts were 19′-4″ forward and 23′-4″ aft. Shortly after the torpedoing on August 13 the drafts of the damaged vessel were approximately 18′-0″ forward and 28′-6″ aft. In less than a week the draft had increased to 29′-6″. The ship had a list of 6° to port. Upon completion of the pumping and shifting of some weights the draft forward was 19′-1″ and aft it was 27′-1″. The list had been reduced to less than 1°.

At 0728 on August 29 the empty S.S. *Mark Hopkins*, on her way back to San Francisco, which had been ordered to come alongside and take our cargo, arrived. Her drafts at that time were 10′-8″ forward and 13′-3″ aft The two ships were lashed together with camels between. The main steam line of the *Mark Hopkins* was connected to that of the *DeYoung* by piping and a six-foot length of 2″-flexible tubing between the ships. (Figure 4.)

The teaching of the personnel on the *DeYoung* to become winch operators and deck hands was accomplished by the First Mate. Merchant sea-

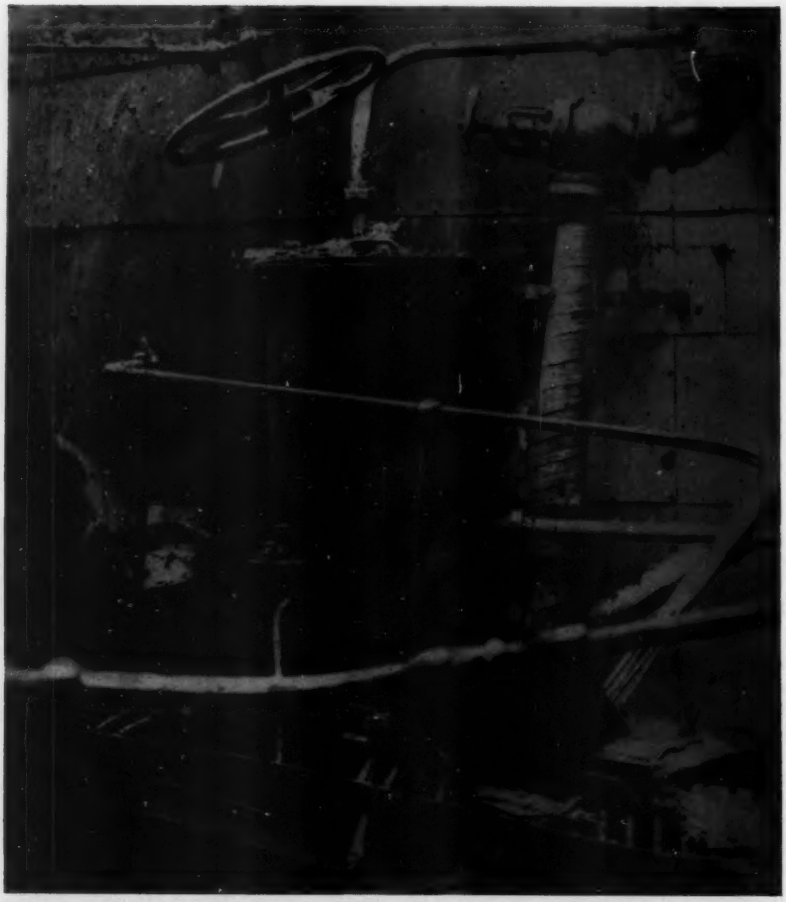


Figure 3. The engine room of the S.S. M. H. De Young as seen from the Upper Deck engine room door.

men and officers and men of the U.S. Navy vied with each other in operating winches. They kept a record on the house bulkhead and considered it a game. The only damage caused by their operations was when the *De-Young* listed under a heavy load and the steam pipe from the *Mark Hopkins* pushed the fender of a jeep on deck downwards about 3 inches. These men were truly marvelous in all respects.

Before transfer of cargo could be effected, technicalities stepped in. The winches started at 1700 on August 29 to remove hatch covers and beams. This took about an hour. Then the noisy ships became suddenly quiet.

I investigated immediately and found the Master and the First Mate engaged in conversation near No. 3 hatch. The Master informed me that our first lift, a heavy piece of machinery, weighed about 1,600 pounds more than the capacity of the jumbo boom. This was understandable, and it was indeed fortunate that no lifts exceeded the weight of the first lift, as the loading of this vessel was accomplished by, and the unloading was contemplated by, good port facilities. The Master informed me that he could not, under law, permit a rated boom to lift a heavier load. We discussed the matter at length, but to no avail. Finally, I gave him until 0800 the next day to accept one of two letters which I would bring to his cabin. One letter

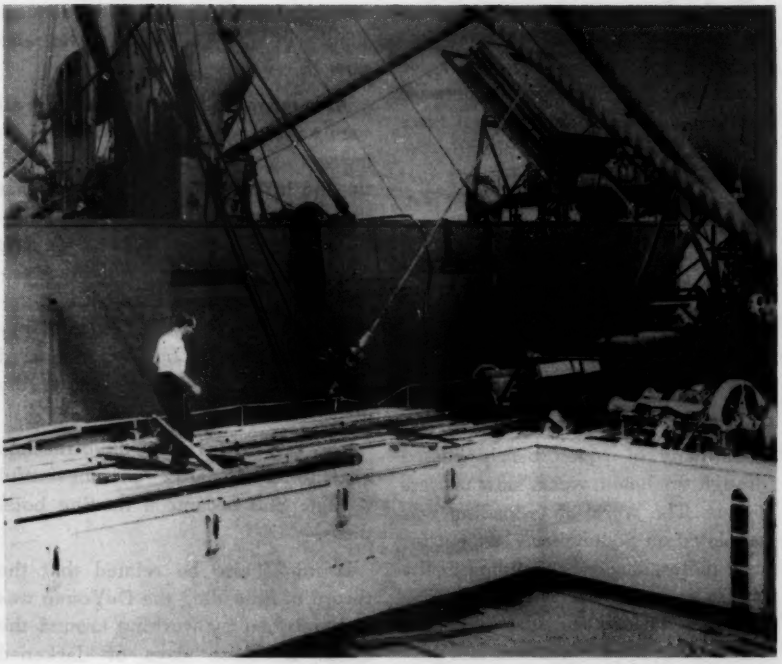


Figure 4. Transferring cargo at sea. The man is walking the deck of the S.S. Mark Hopkins.

would quote pertinent parts of dispatches I had received and sent and would state clearly that the U.S. Navy accepted full responsibility for this operation and that, therefore the Master was fully relieved of any and all responsibility. The second letter would state that in view of the situation, as

of 0800 I officially took over the vessel for the U.S. Navy in this emergency, the United States then being at war. I signed both letters and took them to the Captain at the appointed time. He retained the second letter and I destroyed the first. Although relations were a bit strained at first, we parted as good friends. Another warm friend was the Master of the *Mark Hopkins*.

Work was resumed at 0815. It was necessary to use various methods, including yard and stay, to lift, transfer and reload each item of cargo because the booms on each ship did not have sufficient outreach to plumb the hatches of the other. The work had to be planned carefully because of lack of space for "parking" any item. Generally, when it came off the second deck of the *DeYoung* it had to go into the hold of the *Mark Hopkins*. When cargo was taken out of the hold of the *DeYoung* it went tween-decks on the *Mark Hopkins*. Everyone was efficient, but the handling of large heavy objects, many of which barely passed through the hatch, was a slow process at best. The work of unloading was completed on September 7, except for some plates, shapes and piping in the bottom of each hold. The *Mark Hopkins* then headed for Australia. She took most of the complement and passengers of the *DeYoung*. The drafts of the two vessels as they parted were: *M. H. DeYoung* forward 17′-3″, aft 21′-3″ and *Mark Hopkins*, forward 12′-0″, aft 17′-2″. (See Table I.)

We were on our own again. The tug which started out to tow the *DeYoung* was lost, as I recall, due to enemy action. The relief tug arrived on September 14. I placed Ensign L. B. Thomas, CEC, U.S.N.R. in charge of the *DeYoung* with enough Navy men to operate the diesel-electric and air systems. Air was used in the windlass and steering engine in lieu of steam. Hoisting the anchor was a tiresome procedure with a slightly inadequate supply of air. The rudder was also slow in responding.

Arrangements were made so that all such activities as berthing and messing were accomplished in the forecastle and in the poop in the event that the estimates of condition of the *DeYoung* should be in error and the ship were to break in two through the engine room. One of the tasks was to resecure the engine with wire rope because the explosion had either sheared the foundation bolts or broken the pedestal.

The U.S.S. *M. H. DeYoung* reached Espirito safely after an uneventful voyage. She became a floating hotel there.

It might also be related that the record of unloading the *DeYoung* was accomplished by working around the clock. In those days of darkened ships, two Liberty ships lashed together—the *Hopkins* and the *DeYoung* were brightly illuminated with cargo lights on the masts and bridge structures.

TABLE I

TABULATION OF DRAFTS

DATE	U.S.S. M. H. DEYOUNG		U.S.S. MARK HOPKINS	
July 29, 1943	F	19′- 4″	F	
	A	23′- 4″	A	
August 13, 1943	F	18′- 0″	F	
	A	28′- 6″	A	
August 19, 1943	F	18′- 0″	F	
	A	29′- 6″	A	
August 29, 1943	F	19′- 1″	F	10′- 8″
	A	27′- 1″	A	13′- 3″
August 31, 1943	F	18′- 3″	A	9′- 0″
	A	26′- 7″	A	16′- 6″
August 2, 1943	F	17′-10″	F	8′-10″
	A	24′-10″	A	17′- 9″
August 3, 1943	F	18′- 0″	F	8′- 5″
	A	23′- 0″	A	19′- 1″
August 4, 1943	F	18′- 3″	F	8′-11″
	A	22′- 0″	A	19′- 0″
August 5, 1943	F	17′-10″	F	10′-10″
	A	22′- 0″	A	17′-10″
August 6, 1943	F	17′- 4″	F	11′- 6″
	A	21′- 5″	A	17′- 4″
August 7, 1943	F	17′- 3″	F	12′- 0″
	A	21′- 3″	A	17′- 2″

WHAT'S AHEAD IN ENGINEERING EDUCATION?

ACKNOWLEDGEMENT

This article describes three different forms of engineering education in use in this country today. Part I, dealing with the four-year program, was written by Dr. J. F. Downie Smith, Dean of The Division of Engineering, Iowa State College, Ames, Iowa. Part II, which covers the five-year program, was written by Dr. S. C. Hollister, Dean of The College of Engineering, Cornell University, Ithaca, New York. The unified engineering curriculum, which has made its appearance on the West Coast, is covered in Part III, written by Dr. L. M. K. Boelter, Dean of The College of Engineering, University of California, Los Angeles. The article appeared in the November 1953 issue of "General Electric Review."

I. FOUR-YEAR ENGINEERING PROGRAM

Perhaps we ought to define what is meant by a four-year engineering program. Such a program accepts students with specific entrance requirements, and if they are able to complete satisfactorily a prescribed course of study, it is possible for them to graduate in 12 academic quarters, or eight academic semesters, or four academic years. This might be called "par" for the course. Golfers realize that a few break par, more approximately equal it, and many more aren't quite that good.

Actually, the percent of students finishing in four academic years at some engineering schools is quite small. However, the term is readily understood.

In this country at present the great majority of engineering colleges operate on a four-year plan.

That only a small percentage of those who start the course finish in the specified four years has been used as an argument for the five-year program; and it has been urged that if it takes more than four years for the average student to finish anyway, we might as well be honest and say that it is a 4½- or five-year plan. But as soon as anyone sets up a five-year plan, the program becomes crowded each year, and the slower students would take still longer to complete the work.

Many educators, including myself, believe that the engineering program for many students should contain more than four years of training beyond the high school level; but there is a question whether this more-than-four years should finish at the bachelor's level. At the present time, for example, many of the four-year

schools offer graduate work leading to the master's degree, and some to the doctor's degree. The master's degree generally requires a minimum of one year beyond the bachelor's degree, and the Ph.D. or equivalent, at least three years beyond the bachelor's degree. Thus, in such schools it is possible for a student to take any number of years that he needs to get the education he wants. Also, in some colleges the advanced work may be pursued by the student who expects to go into the practical aspects of industry, as well as by the student who is training for research.

College Analogous with Business

For our purposes let's consider a college, to some extent at least, as a business. Perhaps we might illustrate by a greatly oversimplified simile.

A department store may have the most modern salesrooms, the best-looking and most efficient salesgirls, and excellent merchandise and still be a failure as a business. What really determines its success *as a business* is the ability to sell goods at a profit. Some stores may be staffed by men with vision, who see what the public *should* buy, and who can see that what they recommend and have in stock would be better in the long run than what the public actually buys. And in the end the public may realize the wisdom of these men in foreseeing the demand. But this is of little consequence to the company if it has gone bankrupt in the meantime. The lesson may be appreciated, of course, by other stores.

Fortunately, engineering college administrators are a sensible group of people who keep their feet on the ground remarkably well. There are a few colleges with new approaches to the training of engineers. I am personally very strongly in favor of such programs, and believe that they should be encouraged by engineering educators and by industry. Some of them may be outstanding successes, some only so-so, and others outright failures. We all ought to profit from the results. But the large majority of engineering colleges cannot be of an experimental nature—too much depends on the output; and, until something more satisfactory is developed, most colleges must stay with a system which has been demonstrated over the years to be reasonably satisfactory. Of course, this does not mean that changes in courses, or curricula content, or methods of instruction cannot be modified or changed completely. Such changes are frequently desirable and even necessary. Certainly, at the present time major improvements are called for in the curricula of several engineering departments, but within the scope of the customary length of four years.

Of course, it would be disastrous to have all colleges tend towards a dull uniformity in curricula—and there actually is a tendency in this direction. On the other hand, there is an awakening of the realization of some stagnation, and efforts to change this are being made.

Also, it might be argued that colleges are not a business, and thus business criteria cannot be used. But that really is just a matter of definition. If the student studying in a college acquires the ability to think clearly and can, and will, apply his knowledge of the fundamentals of engineering and other subjects in a satisfactory manner, technically and morally the college will have been successful, and its product can be sold. If, however, the student acquires a distorted sense of values and has not been tested intellectually at a reasonable level, it might be difficult to convince industry that they want him—especially if something more to their liking is readily available. There are such institu-

tions, but to my knowledge, fortunately not in engineering.

Thus, as I see the picture, there ought to be a few colleges where the approach may be quite different than in the others. These more or less experimental colleges might have longer or shorter curricula than the conventional ones, may teach from a totally different viewpoint, may emphasize more fundamental and less practical subjects or vice versa, may stress more of the pure science and less of the engineering phases, and so on. Some of the experiments will be failures, and others complete or partial successes. Because of the natural desire to be on a winning ticket, other colleges would tend to emulate the successes, and thus change can come about. But there will probably be several successful experiments, thus tending to eliminate the trend towards complete uniformity.

Emphasis on the Fundamentals

It is evident that, because of the increasing complexity of engineering devices and rapid advance in science, future engineers will have to be better trained to handle the more difficult engineering problems that will be assigned to them. Thus, it is my conviction that more and more engineers will spend more than four years in college; but again I should ask: "Does this mean at the bachelor's level?" It seems to me that there is sufficient flexibility in the four-year program to permit the study of advanced engineering at the graduate level.

The changes that have taken place in our society during the past 50 years have been such as to decrease the age at which a man retires and to increase the age at which he starts productive employment; this in turn means a constantly decreasing period that he is productive in industry, Industrialists recognize that the sooner the engineer can be made available to them, the more productive life he can offer them. Because much of the technique used can be obtained in industry at least as well as in college, there is a growing feeling that engineering colleges should stick to the so-called fundamentals and leave the applied material to industry.

We realize that everyone's idea about the meaning of the fundamentals is different. Nevertheless, the broad picture is clear. Many applied courses taught in engineering colleges are not in themselves actually used by the engineer in practice but undoubtedly help in his training.

Although it does seem as if some progress can be made in eliminating applied courses, this can't be carried too far. After all, there is a distinction between an engineer and a physicist —a distinction that lies to some extent in the engineer's training in economic design, production, and construction.

Some steps in the direction of streamlining programs can be achieved by the elimination of duplication. For example, in the physics course that most engineers take there are several sections including heat, optics, electricity and magnetism, statics, and others. Some schools think there is needless duplication in having electricity and magnetism taught in the physics department and then repeated, with somewhat different emphasis and perhaps different symbols in the electrical engineering department.

Similar comments have been made regarding the duplication of the teaching of heat in physics, and thermodynamics and heat transfer in mechanical engineering or in chemical engineering. Duplication is also evident in the teaching of statics in physics and later in theoretical and applied mechanics. Of course, repetition may be necessary to ensure that

the student really understands and retains the subject matter.

Planning with High Schools

To me another profitable prospect for conserving the time of the students would be to make an analysis of the complete program from the beginning of high school through the four-year engineering college program. Since engineering colleges get a very small percentage of high school graduates, the problem would not be too easy for the many small high schools in rural areas. But some progress can be made. Some steps already taken in this direction show a distinct possibility of saving time if proper coordination could be obtained. Some states have made definite efforts to improve the situation; it is my opinion that in the long run this will be necessary if we are seriously to consider the welfare of the student and the cost of education to the individual, to society, and to the state.

Social Humanities

A strong argument for increasing the length of the engineering program is to broaden the engineer's viewpoint of civic, national, and international affairs so that he may more actively participate in such activities. After watching the progress of many undergraduates in college, I question whether undergraduates below the junior level are mentally and emotionally prepared for a serious consideration of many of the social humanities. In my opinion a graduate student is more likely to be interested in the social humanities than the undergraduate engineering student. It takes maturity to develop that interest. Thus an alternate suggestion having considerable merit is to offer additional social humanity subjects *after* the student has graduated in engineering. At least one college is proposing this seriously. Of course, during the undergraduate period the student would also have to take some of these social humanities.

With the present scarcity of engineers and scientists, this is probably an unwise time to increase the length of the average engineer's formal training. It is quite possible that if we had teachers with the proper viewpoint and breadth of training, they could interject social humanities at the same time they are teaching technical subjects. If that were done, I believe the undergraduate engineer would be more receptive of the various humanities to which he is exposed. But such teachers are not too plentiful.

As time goes on I am convinced that professional engineers will require a higher degree of technical training and greater knowledge of physics and chemistry than are now ordinarily required for a BS in engineering. In addition, I am convinced the engineer should not only take a specified number of courses in the social humanities, but he should also have a greater appreciation of what the teachers of those subjects are trying to do. At the moment, there is a question whether the average undergraduate really does appreciate them. Where outstanding teachers are available, there is considerable stimulation to the student, but this situation is not universal.

Attaining Professional Level

The engineer should not stop his training at the bachelor level if he expects to go into the higher branches of technical achievement. Among those higher branches we might consider engineers engaged in design, research, college teaching, consulting work, and a few other categories; but it should be remembered that far more engineers are used in positions that do not require a knowledge of the more advanced phases of engineering. Thus, unless the engineer's objectives are changed, a fairly large percentage

of engineers will limit their training to a four-year period. Those who are scientifically able and so inclined should carry on to graduate degrees and should be encouraged to do so, even though this might sometimes involve subsidization through scholarships or fellowships.

Nor should the training of the engineer stop when he gets to industry—to industry falls the responsibility of continuing the engineer's training so that he can become the real professional that he is not at graduation. Some 200 companies in this country have training programs, and the number is increasing rather rapidly.

Technical Institutes

Because of the increasing amount of subprofessional work now being done by engineers, a proper screening of the utilization of engineers is definitely in order. Many engineers in industry are presently engaged in work that could be done by a technician. In my opinion this percentage is larger than most people realize, creating a crying need for more technical institutes to train those men who do not expect to become professional engineers. If such men were now available in sufficient quantities, I believe that there would not now be a scarcity of engineers, although there would still be a serious need for very competent engineers to handle the difficult engineering problems that confront industry.

Industry has the responsibility of utilizing the engineer to his maximum effectiveness and ability. It is quite possible that to achieve this end engineering colleges may have to develop more work of the graduate nature in the engineering extension services throughout the country. A good start on this has been made, but a large amount still has to be done.

New Approaches

Engineering education in this country is in a state of flux: several new approaches to the teaching of engineering are being proposed, and some are under way. I am heartily in favor of new or different methods and techniques, and I'm encouraging them in my own college. But a change away from the traditional four years for the average undergraduate engineer would require more convincing arguments than have yet been put forth.

For the better students or for those who expect to go into the higher branches of engineering, additional time can and should be spent at college, either at the graduate level or in study of nontechnical subjects. The present needs of the country are for more technicians who can handle some of the subprofessional work of the engineer, for the large majority of engineers to be trained in four-year undergraduate programs, and for a growing percentage of engineers to go into the more complex phases of engineering, trained at the graduate level.

Also, steps should be taken to achieve closer co-ordination in the eight years of high school and college with the thought of better utilization of the time.

II. FIVE-YEAR ENGINEERING PROGRAM

In 1938, Cornell undertook an innovation in undergraduate engineering education by adopting an integrated five-year program leading to a first degree. This program began in chemical engineering only, by six years later the engineering faculty voted to extend it to all branches of the profession, that offered undergraduate curricula. Prior to 1938

some schools offered combinations of liberal arts and engineering, often leading to two degrees; but in these programs the engineering content was not more advanced than in four-year curricula. Optional five-year programs leading to a professional degree were taken by a few students, the great majority, however, electing the shorter programs.

Weaknesses of the Four-Year Program

The main reason for the adoption of this program at Cornell was one growing increasingly more evident: The current four-year programs in engineering were not adequate in our opinion to provide the professional education required of the new generation of practitioners in the expanding field of engineering technology. A number of industrial companies whose businesses depended on good engineering put into operation technical training programs calculated to elevate the level of engineering education of its technical staff.

These were not aimed at the research staff alone but were applied to the entire engineering force. Companies that tried them concluded that such programs pay off—in benefits both to the individuals and to the company. The fact that industries engage in basic technical education indicates to educators the inadequacy in the typical college engineering program.

Different ways to strengthen the educational program were reviewed. The obvious one—involving a BS after four years and an MS after a fifth year—was considered. Every engineering student could not be compelled to take the needed fifth year—and four years was not enough.

But inherently, another weakness existed that would be less apparent to the entering student or to most parents. Four-year programs are designed to terminate in four years. The amount of basic science and mathematics is thus limited; this in turn limits the nature and depth of the subjects that can be taught in the last two years. If the subjects that could not be covered in the four-year program were added in a fifth year of graduate work, the scientific and mathematical foundation would not be strong enough to support the level of these subjects. Another year would be required to provide the sequence necessary for both prerequisites and advanced courses—the reason why the master's degree usually cannot be earned before the end of the sixth year in the stronger schools. A program of desired strength involving two degrees could not therefore be given short of six years, unless the whole operation could be integrated and streamlined in the interest of saving the student's time.

Program Possibilities

The plan commonly referred to as the "three-and-two" program—three years in liberal arts (including mathematics, physics, and chemistry) followed by the last two years of a four-year engineering program—was another possibility. The engineering content is no different in the last two years than in the four-year program; and three years are used in presenting the work normally given in the first two years in engineering. If the work is divided between two institutions, such a plan puts the basic training in the liberal arts school where frequently it is better taught but where motivation towards engineering and engineering methods is likely to be lacking. Further, advanced-level engineering-science preparation cannot be set up in the liberal arts college in this pattern without specially designed curricula.

Still another advocated plan is to make all engineering a graduate program. Its many admirable features in-

clude the maturity of the student, the broader general educational background, and the natural elimination of the indifferent or incapable student. Such a radical departure is not feasible at present, however, because it's too costly in both the student's time and money. Moreover, any student who wants this program can follow it under present curricula. But the profession has not yet arrived at the point where such an educational pattern may be required of all engineers.

Affecting a choice of educational pattern at Cornell was the necessity of preserving a broad background in the arts and humanities. If such education is to be effective, it must be gaged to the advancing maturity of the student. It is not appropriate, for example, to give a course in banking or labor relations to freshmen or sophomores who have not had an adequate preparation in economics or psychology. To us this precluded an effective two-year pre-engineering course followed by technical work. It indicated, instead, a sequence of courses that could be given with due regard to prerequisite subjects and to the growing ability and experience of the student.

Broad vs. Specific Training

Why not give a more specialized program in the last two years, thus making room for growing requirements at the basic level? This is the "option" system followed now by so many schools. In electrical engineering, for example, one would select either the power, electronic communications, or illumination option. Again, our faculty was unable to accept such a pattern: experience told them that no junior could say with certainty he was going to devote his professional life to any one of these fields, and they were convinced that these options strengthened each other if taken together in producing a well-rounded education for an electrical engineer.

Permeating the entire atmosphere of the faculty's consideration was the conviction that engineering education should consist of thorough mastery of a broad range of principles rather than training in specific types of computing and formula application. The student in college today will reach his prime 20 years after graduation; surely by that time many of the problem-solving and handbook techniques will be obsolete. The only certain sustaining potential in technical education therefore lies in a thorough grounding in the sciences—both basic and applied.

The Five-Year Program Evolved

Thus the faculty concluded that for a sound professional engineering program in which both a strong technical content and general education background would be maintained the curriculum would have to be lengthened to five years in such a way as to preserve maximum educational effectiveness and minimum expenditure of time for the student. Two parallel stems were thus set up—one technical, the other nontechnical—and each of these was carried through the five years.

Some surprising results came from the streamlining of the curricula: Undesirable overlaps inherent in four-year programs because of restrictions on sequence of courses were eliminated with a saving in time. And the sequential arrangements improved the pedagogical character of subject presentation. An extension of both technical and nontechnical content was thus possible.

An engineering curriculum is divisible into four main parts . . .

Basic sciences—chemistry, physics, mathematics, biology, and others.

Applied sciences—thermodynamics, fluid mechanics, electric circuit theory, mechanics, properties of

materials, electronic theory, and others.

Engineering applications—radio, servo - mechanism, high - voltage techniques, machine and structural design, and others.

Nontechnical courses — English, economics, public speaking, history, languages, and others.

Curricula of different colleges emphasize these four components in varying degrees and widely varying depths. In the training of engineers for the future technology, emphasis on basic and applied sciences is essential. At Cornell basic science extends through the first two years, with calculus available in increasing degree. All students get some physical chemistry, and most get organic chemistry. Dynamics is taught using vector analysis and differential equations. Mathematics at this level is also available for fluid mechanics and thermodynamics, studied by students in all curricula. Likewise, nearly all students take work in electronic tubes and circuits. The main point is that usually the fundamental background in the basic and applied science field is in all curricula, occupying most of the time in the first three years. This recognizes that the principles behind different branches of engineering are much the same; and broad, solid training in them increases the ability of the engineer to work on problems overlapping and interlocking among various fields.

Functions of the Engineer

It is not possible to write a job classification for an engineer in the same way that it would be for a specific craft function; he deals primarily in ideas, and his job is to take certain ideas and bring them into effective form so that others may accurately produce a useful structure, machine, or process. In this respect engineers' ideas differ from those of men in other fields— they are based on physical sciences and mathematics, and must meet certain functional and economic requirements in a manner that maintains safety to life and property. The function of the engineer is essentially the initiation and prosecution of a detailed conceptual process, followed out with such precision that when the operation is begun the performance will be in accordance with forecasts, both technically and economically. Some call this integrated conceptual process *design;* others call it *development.* Whatever the name, it's the heart of the engineer's function.

Building a curriculum to enhance creative imagination is necessary to develop a truly professional engineer, one who can "engineer" structures, machines, systems, or processes into existence. But the necessary ingredient is not so much the title or subject matter of a course as it is that quality of the staff that vitalizes and inspires the student. The beginning may be made in freshman drawing where routine drafting techniques are abandoned in considerable measure for spatial visualization, followed by problems requiring projections of visualization or creativity. Problem courses throughout the curriculum may be so slanted that each solution can be thought of as a method of attack and a process of synthesis leaning upon previous basic knowledge.

In some schools of architecture there is no course in drafting as such. The student acquires this during a course in design in the same manner that slide-rule techniques are learned during computations of problems in engineering courses. Also in architecture there is a sequence of design throughout the full curriculum.

Faculty Requirements

A curriculum with such objectives requires a faculty with qualities be-

yond those of routine training and methods beyond those of repetition. It must be an inspired and inspiring faculty who believe in the great future need for strongly trained professional men, mentally vigorous and capable of stimulating the students' best efforts. It requires balance and blending between scientific attainment and practical engineering experience.

Clearly, it would be a mistake for all schools to undertake immediately a more advanced educational program of this type. Only those equipped with the necessary staff and facilities and having experience in high-level engineering and science training should undertake it. After watching the performance of the graduates in the field it is equally clear however that such a program fills a widening need in the profession—a need that in time will require schools intent on supplying men of high engineering ability to adopt advanced undergraduate programs.

Frequently we hear that four years is as long a time as can be spent in obtaining an engineering education. This all depends on what kind of an education one wants, and whether 25 years from now it will meet the needs of a man dealing with the problems of our rapidly expanding technology.

Future Educational Programs

Education is an investment in the future. One invests well or poorly and reaps the corresponding harvest. Medicine, law, and architecture have had to extend their training beyond four years to meet professional needs. In 1952, Cornell initiated the move to lengthen the architectural training program to five years; now all accredited schools are on this type of program. It is believed that perhaps over a 25-year period a group of the leading engineering schools will lengthen and strengthen their programs. Still there will be a need for the four-year schools where emphasis would be more on operation and maintenance functions than would be true in the more professional schools.

The guiding element in the educational growth is the profession's needs —that in the engineering schools must be judged not in the terms of the present but with a sensitive awareness of the expanding professional requirements over the quarter-century ahead.

III. UNIFIED ENGINEERING CURRICULUM

The engineering baccalaureate program is a part of the training and education of the professional engineer that begins in high school and continues for a period of years after the award of the bachelor's degree.

Considerable evidence has been presented that leads to the conclusion that specialization in engineering can be postponed until after the completion of the undergraduate curriculum beginning with an internship program in industry or through a carefully planned professional graduate program.

A unified undergraduate program has been found to be adequate for employment in both the large company that often provides the opportunity for on-the-job specialized training and the small company where the young employee is asked to solve a great variety of problems for which a broad basic training is necessary.

Fundamental Background

The essential task that faces the student in an undergraduate engineering curriculum is to prepare himself to handle specific elementary problems immediately upon graduation and to

TABLE I.

CONTENT OF AN ENGINEERING CURRICULUM

Division by bases and their application

1. Physical sciences
- Chemistry and physics
- Geology (Insofar as it is not descriptive but represents an extension of chemistry and physics)

Content
- Ideal systems, experimental basis of science, and symbolic description of phenomena
- Observation and description (verbal and symbolic) of physical phenomena
- Properties of substances and materials
- Concept of matter and energy; conservation and transformation principles
- Experimental method—mensuration
- Problem solving

2. Biological sciences
- Physiology, psychology, bacteriology, biology, biochemistry

Content
- See (1) above

3. Languages of communication
- Native tongue, Foreign tongue } oral and written
- Symbolic (arithmetic, algebra, calculus, and others)
- Pictorial (graphics)

4. Properties of materials and their sources

5. Application to components of engineering systems, that is, the engineering sciences

Division by force field
- Mechanical—fluids, solids
- Electrical
- Magnetic
- Thermal

6. Methodology
- Methods of reasoning—logical processes; inductive, deductive, analogy
- Modes:
  - Mechanical (utilizing all physical laws except 2d and 3d laws of thermodynamics)
  - Thermodynamic (introducing 2d and 3d laws)
  - Humanic (introducing man)
  - Economic (introducing cost)
- Analysis and synthesis
- Evaluation and maximization
- Experimental and analytical bases

7. Application to engineering systems
- Structures
- Machines
- Processes
- Circuits
- Earth
- Or combinations thereof
- Utilize techniques of systems analysis (operations analysis), that is, synthesis

8. Professional engineering
- Engineering as an art supplemented by engineering as a science
- Ethical, moral, and aesthetic content
- Industrial functions
  - Design
  - Development
  - Research and others

9. General education
- Socio-humanistic
- Literature and history as past solutions to man's problems
- Impact of technology on society

have acquired the background to proceed most expeditiously in the direction that his employment opportunity presents. The former can be provided by several courses in the senior year that serve to introduce the student to the language, the status of knowledge, the state of the art, and specific applications of the general methodology in a branch, or specialty of the various engineering fields. The acquisition of the engineering methodology can be accomplished through a strong unified educational program that includes the discipline common to the different branches of engineering.

The present engineering curricula, as well as the professional activities of the engineer, must be studied to determine the common disciplines and to establish the differentiating characteristics, if any, of the several branches of engineering. I tentatively conclude that the difference between the activities in the several branches of engineering rests only on the different engineering systems normally included in the separate branches.

Differences of technical language and nomenclature have developed around the several systems that can be generally classified as structures, machines, circuits, processes, earth, and combinations thereof. These differences of language and nomenclature should be continuously reduced or eliminated. The unified curriculum will aid in this process. In addition, the state of the art differs not only for each system but may differ greatly with respect to the several members of a given class (say the low-speed reciprocating steam engine in contradistinction to the gas turbine or the jet engine). The unified curriculum can contribute somewhat to the education of the student in the art; however, it is the considered judgment of many educators that this segment of the professional engineer's training can be accomplished more effectively by industry as a part of the industrial experience of the engineer.

Content of Curriculum

The outline, Table I, may lead to the formulation of the essential and common disciplines of professional engineering. It reveals a division of the engineering curriculum in accordance with the bases, the physical and biological sciences, and their applications to engineering. The outline is not presented in terms of subject material but rather in terms of the framework of science and of engineering.

The study of the present curricula in terms of this outline, as well as in terms of an outline based on subject material, will greatly illuminate the present state of engineering education. The unified curriculum has been developed with the content in mind as presented in the outline.

A cardinal principle of the effective utilization of knowledge is the recasting of segments thereof into other immediately useful subdivisions. To place the entire responsibility of recasting knowledge upon the student or the engineer-in-training proves to be an excessive burden. The formulation, generalization, and integration of fragments of knowledge as made available either through scholarly work in the university and college or in the industry is one function of the engineering faculty.

In a new curriculum the content of all courses should eventually be changed. These changes can be effected slowly. For instance, strength of materials (the mechanics of materials) and analytic mechanics have been combined reminiscent of an earlier day. An attempt is also being made to place mechanics on an experimental experience basis and to reduce the present emphasis on "problem solving." The mechanics of fluids and

solids are presented more intimately than is possible if their segregation in different teaching units exists. Heat-power illustrations of thermodynamics have given way to the presentation of thermodynamics with emphasis on the mode of reasoning introduced with the second law. The techniques of circuit analysis are applied to systems other than electrical.

Considerable attention is being given to the continuity of student experiences, thus no time gap exists between the instruction in mechanics in the physics courses and the introductory course in mechanics as administered in engineering.

Several experimental additions are being made to the engineering curriculum. The base upon which engineering instruction is being built is being extended to include the life sciences as well as the physical sciences, particularly physiology and psychology. A one-year course in biotechnology is available in which the laws of physics, chemistry, and biology are applied to man, and the interaction of man with the environment created by the engineering system (machine, process, circuit, structure) is studied. Thus the engineering student will be partially grounded in the behavior of animates, particularly man, as well as in the behavior of inanimate objects and systems.

These biotechnologic course experiences are, and must be, followed by their application in subsequent student activities and courses. Knowledge of the basic considerations relative to man provides a setting that increases the meaningfulness of latter courses and experiences that revolve around supervision, management, labor relations, and sales problems.

A one-year course in the statistics of engineering has been introduced as an elective. Most engineering students complete this course which allows the analysis of systems not amenable to those techniques included in the orthodox courses in mathematics. It is to be noted that this course is not an introductory course in statistics, nor is it a problem-solving experience. The background acquired by the student leads to the graduate operations-analysis offering in which typical engineering systems are analyzed and synthesized.

Engineering works are wrought in materials. The properties and uses of materials receive concentrated attention. The several materials are studied; their properties are observed separately and in place. That is, the mechanical, electrical, magnetic, thermal, and other properties are brought into focus and then their interrelations noted. Again the properties and behavior of living tissue and bones are presented together with those of the usual "engineering" materials.

Analytic and Experimental Approach

Solutions of engineering problems are found through the use of analytic methods (derivations and calculations) or the use of experimental methods, or the judicious use of both. The student must be capable in the experimental method upon graduation. The parallel learning of the two methods (analytic and experimental) by the student is important.

The laboratory exercises then become more than demonstrations of the behavior of physical, chemical, and engineering systems; they become a workshop in the applications of the methodology of experimental solution. In brief, the experimental basis of engineering is brought into relief. The laboratory course activity also includes experiences in management, communication, and semantics.

The laboratory courses will provide experiences in mensuration and instru-

mentation, properties of materials, unit operations, and engineering systems, with the major emphasis on each of the subdivisions noted above in the freshman, sophomore, junior, and senior years respectively, but with each of the four subdivisions being represented in the other three years.

The term unit operation implies experiment stations describing a particular physical- or bio-phenomenon—for instance, flow of a fluid through a channel or over a surface; behavior of a circuit containing inductors, capacitors, and resistors; or absorption, transmission, and reflection of radiant energy. On the other hand, the engineering systems will be complete replicas (models or prototypes) of actual industrial systems. Complete power plants (steam and diesel), a production system in which a small pulley is produced, an irrigation system, a sewage reclamation plant, and a radio station are listed as examples of engineering system already available or in the planning and construction stage.

The production system will be illustrated. Strap iron and bar stock are subjected to a cutting and punching operation (punch press) and to a turning, cutting, and drilling operation (automatic tool) respectively; assembly is accomplished and the parts are brazed together, forming the pulley. The accuracy of the product is established through the use of appropriate gages, and manufacturing tolerances are met. An economic analysis is made of the process and another is proposed and subjected to economic scrutiny by each student group.

Other Unifying Courses

Several other unifying courses will be introduced in the senior year at an early date. The first will include a discussion of natural resources, their availability, depletion or accretion rates, and the associated processes. The resources considered are air, soil, water, minerals, sea, plants, and animals (excluding man who is presented in the earlier courses). The second will be a course in system engineering that will be taught by the case method and in which the synthesis of components and the maximization of a production (or construction) sequence will be illustrated. In this course the student will obtain his first glimpse of the activities of a professional engineer. A course in modern physics that will be required of all seniors and that will replace in unit value certain of the freshman-sophomore physics course material is also in the planning stage.

Many more details could be given relative to the teaching methods employed, recasting of courses, and future plans, but these will be omitted.

The extensive engineering correspondence and engineering extension activities, as well as graduate work, are planned to bring the materials of an engineering education to the engineer-in-training and the professional engineer employed in the industry. Many of the courses are designed specifically to meet the needs of the engineer in industry, and the instructors more often than not are experienced professional engineers.

The graduate program leading to the MS and PhD degrees consists of courses on and near the campus, both day and evening, as well as work leading to the MS degree at two off-campus stations located at Inyokern and San Diego. Again, a segment of this program is designed for the employed engineer. Upgrading through engineering education is a conservator of technical manpower.

THE EFFECT OF ROUGHNESS CONCENTRATION UPON THE FRICTIONAL DRAG

DR.-ING., SIGHARD F. HOERNER

THE AUTHOR

(known by his book on "Aerodynamic Drag") studied Mechanical Engineering in Munich (Dipl. Ing.), received a degree of Dr.-Ing. in aerodynamics in Brunswick and a degree as Dr.-Ing.habil. at the Institution of Technology in Berlin. He then did aerodynamic research in the DVL (which is the German equivalent of the NACA); he also was the principal aerodynamicist connected with the development of the Fieseler "Stork"; he was for a time head of design aerodynamics with the Junkers Corporation, and served finally as research aerodynamicist in the Messerschmitt Corporation. On invitation by the U.S. Air Force, Dr. Hoerner came to this country in 1946, was in the Wright Field establishment as an aerodynamicist and is now engaged in research for the U.S. Navy's hydrofoil-boat project as an employee of Gibbs & Cox, Inc. in New York City.

ABSTRACT

Schlichting's findings on the drag characteristics of rough surfaces, predicting constant terminal drag coefficients have not been found confirmed on certain kinds of rough surfaces, especially in the field of shipbuilding. This paper analyzes available experimental material and comes up with the roughness density as the main parameter through which existing discrepancies can be resolved.

CONSTANT DRAG COEFFICIENTS

Since Nikuradse's experiments on rough pipes (1) and Prandtl-Schlichting's work (2) on rough surfaces, the skin-friction drag due to sand roughness is fairly well known. The essential feature of this drag is that the non-dimensional coefficient $C_f = D/qS_{wet}$ assumes a constant level above certain "critical" Reynolds numbers which shall be called "terminal." These numbers and the level values are an experimentally known function of the grain-size ratio k/ℓ, where ℓ = length of the considered surface. This law has also been found applicable to certain dull-painted surfaces (3) and on slender wing sections (4a) and bodies (4b).

In a second paper (5), Schlichting has presented further experimental data, this time dealing with roughness elements whose shape and concentra-

tion are different from the previously investigated sand roughness. The results, which are established only for a very small Reynolds-number range, are presented in the form of drag coefficients and equivalent sand-roughness ratios; that is k_s/k, indicating that the respective kind of roughness (with height or diameter k) has the same drag coefficient as a sand roughness with grain diameter k_s. Doing this, Schlichting had evidence that he had passed in his experiments the terminal transition range (from smooth-turbulent to roughness flow of the boundary layer); the constancy of the coefficients was, however, rather assumed (in analogy to that of sand roughness) than established.

Figure 1 shows Schlichting's and other (6) findings plotted against the density ratio

$$\sigma = \frac{\Sigma(k^2)}{S_{wet}} \qquad (1)$$

As the density is reduced from $\sigma = 100\%$, drag coefficient and "equivalent sand-roughness" ratio increase first. The lower halves of the spherical sand grains, which are the basis of comparison, are of no significance at or near $\sigma = 100\%$; here, half spheres evidently have the same hydrodynamic effect upon the boundary layer as whole spheres. Decreasing the density, a maximum is reached and subsequently the equivalent sand-grain size decreases, approaching zero as the density approaches zero. Schlichting's presentation was amplified by (7) testing "moderately rough surfaces," that is mostly, painted surfaces. Schultz-Grunow says among others that the final constant level of the coefficient had not been reached in his tests, that a "special method" was employed to find the equivalent sand-grain size. At any rate, he again assumes that constant terminal drag coefficients will be reached by the investigated kind of roughness, without having proof for this conclusion.

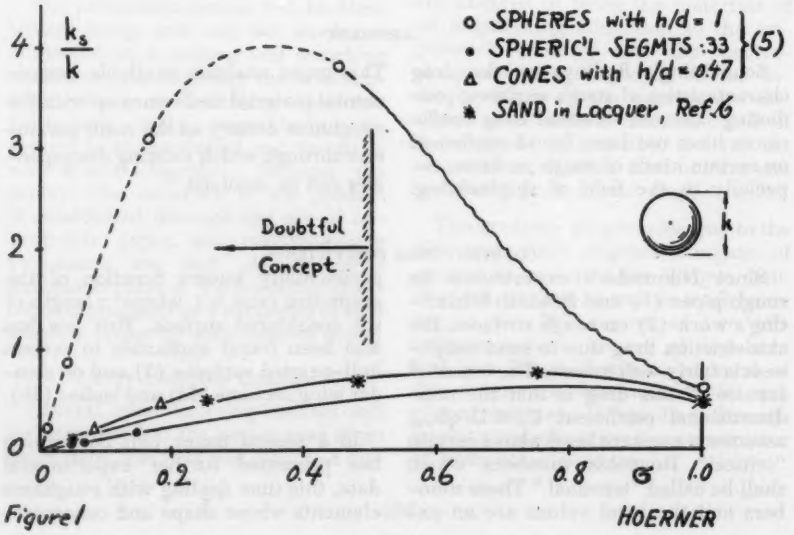


Figure 1

HOERNER

EVALUATION OF EXPERIMENTS

The aerodynamic concept of constant drag coefficients (squared speed law of resistance) was, however, not confirmed

(a) when investigating surfaces covered with a number of rivet heads (8) (9),

(b) when testing certain types of painted surfaces (10),

(c) according to experience with full-scale ship-trial results (6).

Available results of this kind are plotted in Figure 2. As far as other reasons may be disregarded, the diverging results were correctly laid to the fact that the investigated roughnesses had not been of the "sand" kind.

In respect to density (concentration of the roughness elements on the surface) the NACA conducted tests on a revolving cylinder (12), covered with various numbers of sand grains (of constant diameter). Figure 3 shows:

(a) that the drag functions of the investigated roughnesses seem to originate from approximately one common point of $C_f(Rl)$;

(b) that the slope of the drag coefficient against Reynolds number is a function of the density. A constant value is only evident for the highest densities.

In connection with point (b), the results of Figure 1 are no longer accurate; as far as density ratios below $\sigma \approx 0.6$ are concerned. Possibly, the graph may, however, indicate drag coefficients near a maximum which is located somewhere above the terminal Reynolds number. Figure 4 shows the average exponent of the slopes taken from Figure 3, or the ratio n/n_o, respectively; where n indicating the exponent in

$$C_f \propto R^n \qquad (2)$$

and n_o the exponent corresponding to the smooth surface.

Results on a revolving cylinder can probably mathematically be transformed to conditions on a wall in "free" flow, in a similar way as this has been done (2) when converting pipe results. If a suitable method to this effect can be found, the rotating cylinder may

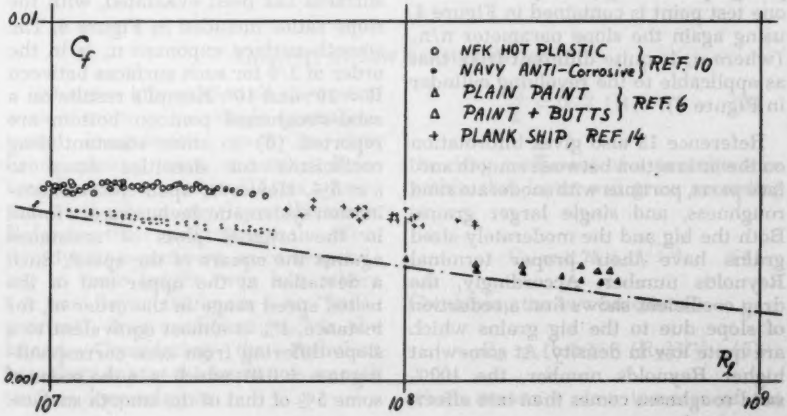


Figure 2

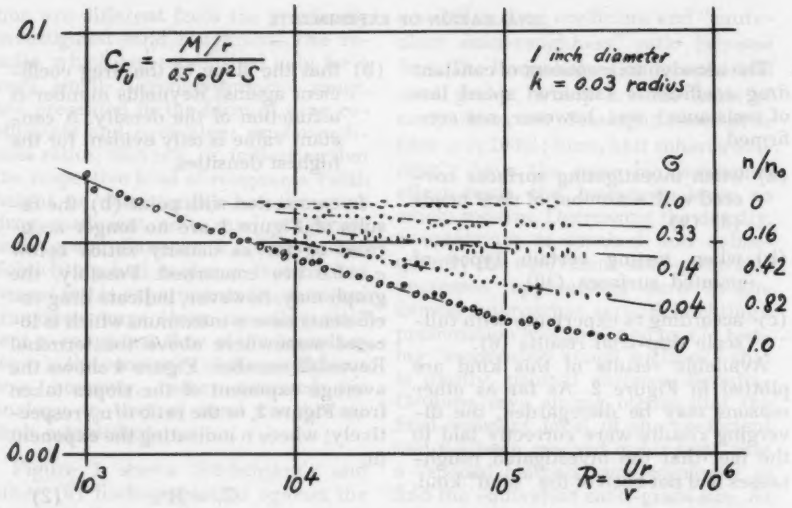


Figure 3 HOERNER

also be a convenient method of testing all kinds of roughnesses with little experimental equipment.

Reference 13 gives experimental evidence on the characteristics of pipe flow for a systematic series of roughness densities. The findings of the last paragraphs are generally confirmed; one test point is contained in Figure 4, using again the slope parameter n/n_0 (where n_0 is quite different from that as applicable to the revolving cylinder in Figure 3).

Reference 13 also gives information on the interaction between smooth surface parts, portions with moderate sand roughness, and single larger grains. Both the big and the moderately sized grains have their proper terminal Reynolds number. Accordingly, the drag coefficient shows first a reduction of slope due to the big grains which are quite low in density. At somewhat higher Reynolds number, the 100% sand roughness comes then into effect; a constant terminal coefficient is finally reached. Any combination of single elements and of smooth or rough surface portions and of rough parts varying in grain size may thus approximately be treated by superposition.

Finally, a number of tests on plane surfaces has been evaluated, with the slope ratios included in Figure 4. The smooth-surface exponent n_0 is in the order of 1/6 for such surfaces between $R = 10^6$ and 10^8. Kempf's results on a sand-roughened pontoon bottom are reported (6) to show constant drag coefficients for densities down to $\sigma = 5\%$. However, upon closer examination systematic deviations are found in the original plots of resistance against the square of the speed. Such a deviation at the upper end of the tested speed range in the order of, for instance, 1% is almost equivalent to a slope differing from zero corresponding to $n = 0.01$, which is in the order of some 5% of that of the smooth surface.

As a consequence, exponent ratios are found which fit into the pattern of Figure 4.—Exponent ratios have also been evaluated for the painted plank body of Reference 10, with density ratios estimated on the basis of reported surface profiles.

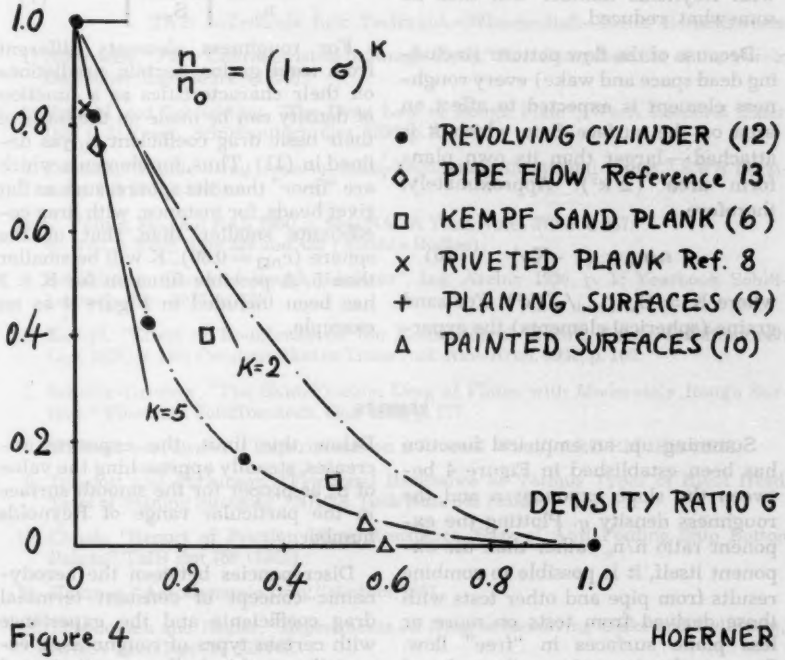


Figure 4 HOERNER

ANALYSIS AT LOW DENSITY RATIOS

Extensive information on the resistance of more or less single or concentrated irregularities such as rivet heads, plating joints or surface holes have been presented in (11) as a function of the boundary-layer thickness. Referring their coefficients to the effective dynamic pressure, as corresponding to their height ratio h/δ, where δ = total layer thickness — an "independent" drag coefficient "c_D" is obtained. Considering the turbulent boundary-layer thickness of smooth surface decreasing as

$$\frac{\delta}{x} = 0.22\ (R_x)^{-1/6} \qquad (3)$$

the drag coefficient of a protuberance within that layer will grow according to

$$C_D = 0.75\ c_D \sqrt[2]{h/\delta} \qquad (4)$$

Combining the two functions

$$C_D \propto (h/x)^{1/3}\ (R_x)^{1/18} \qquad (5)$$

which means a slow increase of the

drag coefficient of this kind of roughness with increasing speed. For a number of such protuberances placed upon a smooth surface, the decrease of the total drag coefficient of this surface with Reynolds number will thus be somewhat reduced.

Because of the flow pattern (including dead space and wake) every roughness element is expected to affect an area on the surface S to which it is attached — larger than its own planform area (Σk^2). Approximately, therefore,

$$n/n_o = (1 - K\sigma) \qquad (6)$$

where $K = S_{affected}/\Sigma(k^2)$. For sand grains (spherical elements) the experimental points below $\sigma \approx 0.1$ in Figure 4 suggest $K = 5$. Between this limiting function and $\sigma = 1$, the test points may be interpolated by

$$\frac{n}{n_o} \approx \left[\frac{\Sigma(k^2)}{S_{wet}}\right] K \qquad (7)$$

For roughness elements different from sand grains, certain predictions on their characteristics as a function of density can be made on the basis of their basic drag coefficient $c_{D\square}$ as defined in (11). Thus, for elements which are "finer" than the sphere, such as flat rivet heads, for instance; with drag coefficients smaller than that of the sphere ($c_{D\square} \approx 0.36$), K will be smaller than 5. A possible function for $K = 2$ has been included in Figure 4 as an example.

RESULTS

Summing up, an empirical function has been established in Figure 4 between the slope exponent n and the roughness density σ. Plotting the exponent ratio n/n_o rather than the exponent itself, it is possible to combine results from pipe and other tests with those derived from tests on more or less plane surfaces in "free" flow. Down to density ratios in the order of 0.6, the exponent is close to zero which means fairly constant drag coefficients. Below this limit, the exponent increases, steadily approaching the value of n_o as proper for the smooth surface in the particular range of Reynolds number.

Discrepancies between the aerodynamic concept of constant terminal drag coefficients and the experience with certain types of roughnesses, especially on ship hulls, are eliminated after introducing the, so far empirical function between slope and density.

CONCLUSIONS

The problem of slope $C_f(R)$ is most important in shipbuilding, chiefly because the gap in Reynolds number between the tank tests (10^7) and full scale conditions (10^9) is in the order of 1 to 100. The analysis presented in this paper and the mechanism of density and slope serve to explain most of the discrepancies felt to be existing in the past, as far as the frictional resistance of ships is concerned. Further experimental treatment of the roughness characteristics of specific paint- or other technical coatings or natural surfaces (fouling) is, however, needed, to establish further, not only the slope but also the "terminal" Reynolds number and with it the mentioned maximum of the drag coefficient (against Reynolds number) as a function of roughness density.

REFERENCES

NACA=National Advisory Committee for Aeronautics

ARC =Aeronautical Research Council

TMB =Taylor Model Basin

ZWB =Zentrale fuer Technisch—Wissenschaft—liches Berichtswesen

1. Nikuradse, "Flow Characteristics in Rough Pipes," Forschungsheft 361 of the Verein Deutscher Ingenieure (1933).
2. Prandtl and Schlichting, "The Drag Law of Rough Plate"; Werft Reederei Hafen 1934 p. 1; Yearb. Schiffbautech. Ges. 1936, p. 418.
3. Doetsch, "Profile-Drag Tests on Mass-Production Sheetmetal Wings," ZWB Document FB 1731 (1943).
4. a. Young, Journal RAS 1950, p. 534; NACA Tech Notes 279 and 457.
   b. NACA Tech Rpts 324 and 432 (Airship Bodies).
5. Schlichting, "Drag of Rough Surfaces", Ing. Archiv 1936, p. 1; Yearbook Schiffbautech. Ges. 1937, p. 159.
6. Kempf, "Effect of Roughness on the Resistance of Ships"; Yearb. Schiffbautech. Ges. 1937, p. 159; Condensation in Trans Inst. Nav. Arch. 1937, p. 109.
7. Schultz-Grunow, "The Skin-Friction Drag of Plates with Moderately Rough Surface," Yearbook Schiffbautech. Ges. 1938, p. 177.
8. Williams and Brown, "Experiments on a Riveted Wing," ARC RM 1855 (1938).
9. Truscott and Parkinson, "Frictional Resistance of Various Types of Rivet Heads Tests of Planing Surfaces"; NACA Tech Note 648 (1938).
10. Couch, "Report of Friction Plane Resistance Tests of Anti-Fouling Ship Bottom Paints," TMB Rpt 789 (1951).
11. Hoerner, "Aerodynamic Drag," Author 1951.
12. Theodorsen and Regier, "Experiments on Drag of Revolving Disks and Cylinders," NACA Tech Rpt 793 (1944).
13. Colebrook and White, Proc. Roy. Soc. A Vol. 161 (1937).
14. Hiraga, "Investigation of the Risistance of Long Planks and Ships," Trans. Inst. Nav. Arch. 1934, p. 284.

STRESSED RUBBER

ACKNOWLEDGEMENT

This article, written by Professor A. H. Willis, was published in the October, 1953 issue of the "Transactions of The Institute of Marine Engineers."

This paper is primarily concerned with the use of rubber as a stress-carrying material. There are many other features of rubber, in particular its resistance to corrosion, which interest marine engineers, and these will be mentioned. Engineers, however, must judge rubber as an engineering material and that leads us to consider first its mechanical properties, which are unlike those of other engineering materials. The engineering uses of those properties will then be considered.

Raw rubber as it exists in the natural state is useless as an engineering material. It must be subjected to many processes before it exhibits the elasticity and resilience which are its chief characteristics. These processes are chiefly the concern of the rubber technologist but two of them are of interest to the engineer; they are compounding and vulcanization. Compounding is the process by which certain chemical substances in selected proportions are incorporated into the mix. Chunks of raw rubber in the form received from the plantation are fed into mixing mills together with the chemicals and the whole is worked or "masticated" into a plastic mass. The chemical substances are sulphur, which is the main vulcanizing agent, the reinforcing materials, chiefly carbon black in high-grade rubbers, and others which accelerate the subsequent process of vulcanization, improve the "ageing" characteristics, and effect other improvements. The mechanical properties of the compound depend to a considerable degree on the proportions of the chemical substances.

The final process in manufacture is vulcanization, or cure, and its function is to restore and improve the elastic properties. It consists of subjecting the mixture to an appropriate period of heating. In the case of molded articles, this is done by placing the mold between the steam-heated platens of a press. The time and temperature of vulcanization also govern the elastic properties of the product and must be carefully controlled.

By variations of compounding and vulcanization, rubber can be produced in an infinite number of forms, from a soft brown material called a pure gum stock, to a hard black material called vulcanite or ebonite which the layman does not consider to be a rubber. This wide variety is one of the main difficulties in rubber design and because of it the engineer must always seek the advice of the rubber technologist before selecting the compound for a particular job. Rubber specifications have

not been rationalized in the same way as alloy steels although some progress in this matter is being made. Often the engineer is faced with meaningless trade names instead of precise specifications and he naturally dislikes being too much in the hands of a specialist. However, undue concern on this score is not necessary because the assistance of reputable rubber companies in any engineering venture is readily forthcoming.

Despite this wide variety of compounds, it is possible to describe the mechanical properties of rubber in general terms. No attempt will be made to describe in detail the behavior of synthetic rubbers. The term is something of a misnomer. In synthetic rubbers, scientists have produced artificially materials which have a similar chain-like molecular structure to natural rubber and which respond to similar manufacturing processes. They were developed in Germany as a direct substitute for natural rubber and by other countries to overcome certain of the disadvantages, such as poor oil-resistance, of natural rubbers. During the war, however, when supplies of natural rubber were cut off, the U.S.A. expanded its production of synthetic rubber enormously, and this production capacity is maintained against a similar possibility in the future. The use of a certain percentage of synthetic in rubber products is mandatory in America. The technical improvements of synthetic rubbers and their decreasing cost make them serious rivals to natural rubber compounds. Broadly speaking, both natural and synthetic compounds show the same general features as regards elastic properties.

MECHANICAL PROPERTIES

The essential characteristics of all rubber-like materials is their ability to withstand severe elastic deformations without serious damage. They have a low shear modulus and a relatively high bulk modulus. In this respect, a comparison with steel is interesting, as shown in Table I.

TABLE I

	Bulk modulus K	Shear modulus C	Ratio $\frac{K}{C}$
Steel	25×10^6 lb. per in.^{2}	12×10^6 lb. per in.^{2}	2.1
Rubber of 50 Shore hardness	0.35×10^6 lb. per in.^{2}	95 lb.per in.^{2}	3,600

The low shear modulus of rubber means that small forces will produce large changes of shape. The bulk modulus of rubber approaches the same order as that of steel, so that it has a high resistance to change of volume. It may be said that rubber is virtually incompressible, and it follows that, in design, provision must be made for the rubber to expand to maintain the necessary constancy of volume. A familiar example is the sealing ring of a wet liner in an oil engine. The rectangular groove must have approximately the same cross-sectional area as the rubber ring so that there is room for the rubber to flow into the corners.

Owing to its large elastic deformations, rubber is an excellent material for isolating vibration. It can store large amounts of energy; whilst a steel spring can store up to 100 ft. per lb. of energy per lb. of material a medium-hard rubber may store several thousand ft. per lb. of energy per lb.

Rubber also shows high hysteresis so that in a vibrating system mounted on rubber there is considerable inherent damping of the vibrations. Another attractive feature lies in the fact that rubber springs can be stressed in several directions. The familiar rubber bush illustrates this (Fig. 1). It is capable of sustaining (a) torsional loads; (b) radial loads; (c) longitudinal couples or "conical" loads and (d) axial loads; and the various loads and couples may exist in combination. By contrast, metallic springs can usually

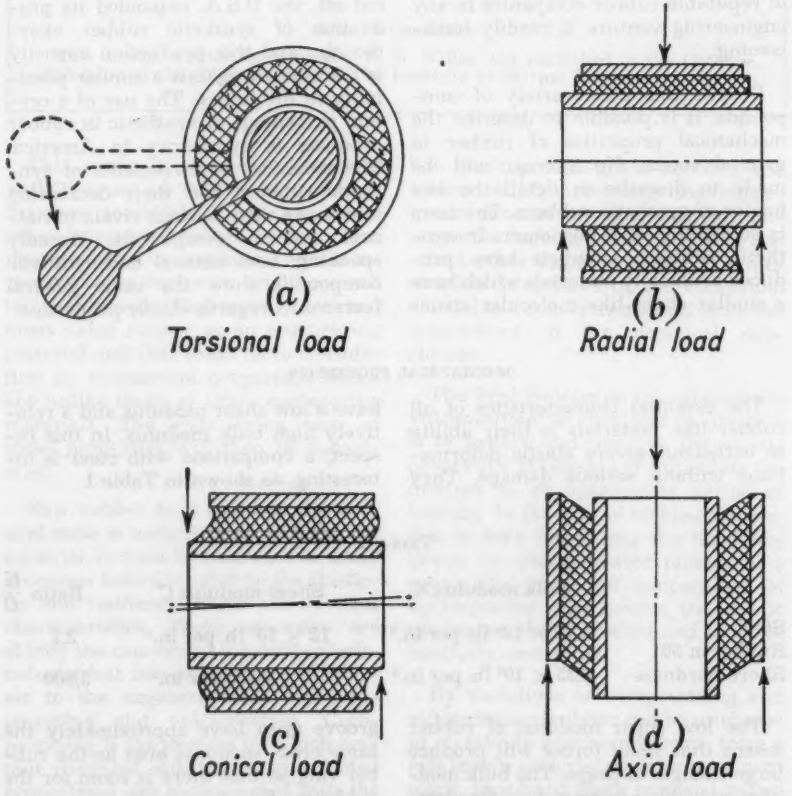


Fig. 1—*Rubber bush under various types of loading*

be stressed in one direction only.

In engineering applications, rubber is usually stressed in compression and shear. In a compression test, a cylindrical specimen takes up a barrel shape. This is due to the friction at the ends which restrains sideways expansion. In all practical applications,

restraint of some kind must exist and it is necessary to appreciate its effect on the apparent stiffness of the rubber; Fig. 2. is an illustration of this.

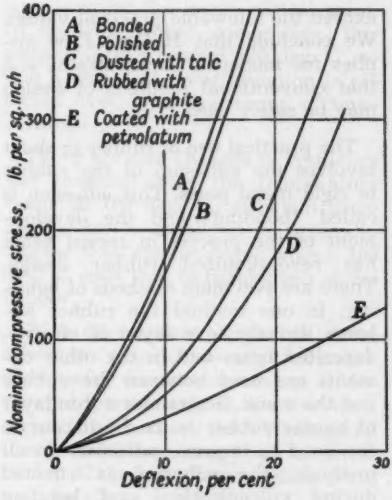


Fig. 2—*Effect of restraint at ends*

It shows the stress deflexion curves for five similar specimens when the frictional restraint at the end faces is varied by means of lubrication. Curve E has the smallest slope; in this case the use of petrolatum allows the ends to expand laterally so that the cylindrical shape is maintained. When the ends are bonded, curve A, there is perfect restraint at the ends and the stiffness of the rubber is greatly increased. Curve B lies very close to curve A and illustrates the high coefficient of friction between dry rubber and steel. (In one well-known make of rubber bush, the frictional effect is relied upon entirely to resist torsional loads.) Curves C and D lie between the extreme curves, the lubrication in these cases effecting only partial end restraint.

Considering this effect further, it will be clear that the relative dimensions of the specimens will change the amount of barrelling; a short specimen will not expand laterally so easily as a longer one, with a consequent effect upon the apparent stiffness of the rubber. As an example, we may compare the apparent compressive moduli of two cylindrical specimens of the same height but of diameters in the ratio of 6:1. It will be found that the modulus of the shorter specimen is about four times that of the longer one for a given deflexion. Unfortunately, the moduli are not in simple proportion to dimensional ratios. This difficulty in design is overcome by the use of empirical shape factors, the most rational of which is that suggested by Kimmich,* namely,

$$\text{Shape factor} = \frac{\text{area of one loaded face}}{\text{total free area}}$$

The author has published charts showing the chord modulus values for 10 and 20 per cent axial deflexion for rubbers of different Shore hardness. Fig. 3 is this type of chart. These

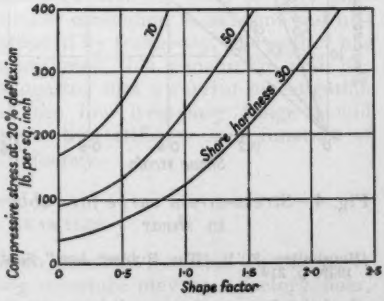


Fig. 3—*Compressive stress at 20 per cent deflexion for various hardness values*

*Kimmich, E. G. 1940. "India Rubber World," Vol. 103, p. 85.

charts are by no means universally used, most rubber manufacturers having their own empirical formulae or nomographic charts. There is a sad lack of uniformity in the various design methods.

RUBBER IN SHEAR

Since deformations are almost wholly changes of shape, it follows that the most logical way to employ rubber is in shear. Shape factor effects are negligible and the stress-strain relationship is linear. Fig. 4 shows the results† of tests on shear mountings for rubbers of different hardnesses. The hardest rubber shows a linear relationship up to 0.1 strain, corresponding to an angular deflexion of 12 degrees, and the softest for a range up to 0.4 strain. These values exceed the allowable practical values. We conclude that Hooke's Law applies for moderate shear strains and that conventional methods of design may be safely used.

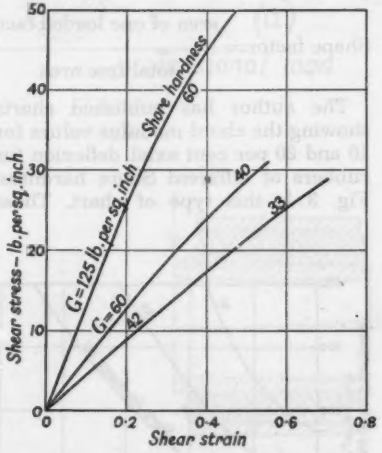


Fig. 4—*Stress-strain curve for rubber in shear*

†Haushalter, F. L. "The Rubber Age," Sept. 1939, p. 219.

The practical use of rubber in shear involves the adhesion of the rubber to rigid metal parts. This adhesion is called "bonding" and the development of the process in recent years has revolutionized rubber design. There are two main methods of bonding; in one method the rubber adheres directly to a layer of electrodeposited brass and in the other cements are used between the rubber and the metal. Sometimes a thin layer of harder rubber is used adjacent to the bond to improve adhesion. In all methods, the adhesion is effected during vulcanization, and bonding should not be confused with "sticking" by means of adhesives applied after vulcanization, which is unsuitable for highly stressed parts. Bond strengths of as high as 1,000 lb. per sq. in. are possible but designers rarely exceed 50 lb. per sq. in. in components under pure shear subjected to alternating stresses. As bonding technique improves, rubber can be more effectively used in vibrating systems.

A combination of compressive and shear deformation is frequently used in practice and unusual but desirable characteristics can be achieved in this way.

TEMPERATURE AND TIME EFFECTS

By comparison with metals, the useful temperature range of rubber is small and, within the useful range, temperature may have some effect upon mechanical properties.

As the temperature of natural rubber decreases from about 0 deg. C., it is found that resilience fails rapidly, and at the same time the modulus increases steeply. The material is chang-

ing in character and behaves more like an ordinary solid, becoming less flexible, harder and ultimately brittle. There is a minimum value of resilience which may be less than 10 per cent and the temperature at which this occurs is called the lower critical point. In natural rubber compounds, this temperature is around – 40 deg. C., so that a complete transformation is effected over a narrow range of temperature.

There are also changes in resilience and modulus over the temperature range 20–100 deg. C., although these are relatively small. It is generally known that temperatures above 100 deg. C. soon lead to breakdown of the rubber.

With oil-resistant synthetics, these effects are generally more pronounced. The useful temperature range is decreased, particularly at the low temperature end, where the stiffening and loss of resilience may begin at about 20 deg. C. and the lower critical point may be above 0 deg. C.

Due account of these changes must be made in design and careful thought must be given to components that operate in sub-zero temperatures.

Time effects reveal themselves in a variety of ways. Under a constant dead load a rubber component will continue to deform after the load is initially applied, thus exhibiting "creep." The rate of creep diminishes with time and for all practical purposes becomes zero after a time, although this may take some hours or days. The converse condition is called "delayed elastic recovery," which means that the initial set at the moment of unloading will decrease as time goes on. With some soft compounds, the permanent set is often negligible after the lapse of a few hours. Yet another kind of time effect is that of "stress relaxation," which means that when a component is kept in a state of constant strain, the stress in it will diminish with the lapse of time. These effects are important in design; for example, when rubber is used in a transmission system, creep effects may cause misalignment.

Perhaps the most important revelation of time effect is in the relationship of dynamic properties to static properties. One may not use without modification data obtained from static tests at slow rates of loading, as in an ordinary testing machine, and apply them to vibrating systems. For example, the stiffness of a particular mounting may be 20 per cent greater than the static value when stressed at, say, 20 cycles per second. Some synthetics show a dynamic to static modulus of as much as 3 to 1. It is commonly accepted that the ratio for any particular compound is constant and unaffected by frequency. The author has questioned this conclusion and has suggested that a careful investigation of the low frequency range would show that stiffness is a function of frequency.

SOME PRACTICAL EXAMPLES

We know from simple vibration theory that in order to reduce the vibration transmitted to a supporting structure, it is necessary to have a natural frequency much lower than the disturbing frequency. This low natural frequency is achieved by mounting the engine or machine on springs of low stiffness. For such springs rubber is an excellent material. The supporting structure may be a factory floor, an automobile chassis or a ship's hull; the principles of design which must be observed are the same.

Most rubber suspensions are rubber-to-metal bonded units in which, under normal running conditions, the

rubber is loaded substantially in shear. As we have seen, rubber has a low modulus in shear. There is always the need to provide for overload and this is done by introducing compressive loading. Overloading frequently occurs at right angles to the axis of the suspension, as, for example, when a ship strikes a jetty. There are many types of patented vibration mountings and one of them is shown in Fig. 5. It consists of concentric conical shells between which is bonded a layer of rubber. As shown, the unit is unloaded. The central member carries the live load, and thus the rubber is under both shear and compression, the compression component becoming relatively greater as deflexion increases. The increasing stiffness as deflexion increases or, as it may be termed, the "rising rate" of the spring, is often a desirable feature. Excessive deflexions in the vertical direction are prevented by the "flange" of rubber at the upper end and by the rebound washer at the lower end. Horizontal forces place the rubber in compression radially, in which respect it is immensely strong.

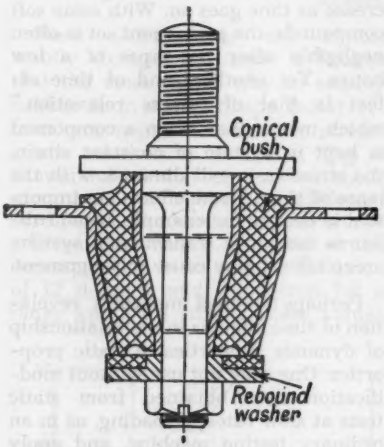


Fig. 5—*Conical bush mounting*

FLEXIBLE COUPLINGS

Fig. 6 shows the Metacone system for mounting flexibly a small marine engine. It also shows a flexible coupling which has the double purpose of cushioning to some extent the torsional loads on the shafting and providing for slight angular misalignment. It must be remembered that the flexible suspension of a marine engine automatically requires flexibility in all other connections between the engine and the hull; moreover, the problems of misalignment arising from flexibility of the engine unit and from possible creep must be solved. Misalignment of the main shafting is not a new problem to the marine engineer.

Connections to the engine must not, of course, be rigid. Fuel feed pipes, cooling water pipes and exhaust systems must be examined from the standpoint of flexibility. None of the problems is difficult to solve even in big craft.

In the smaller sizes of internal combustion marine engines the thrust block is accommodated within the engine. A flexible coupling between engine and shaft must then be able to withstand the axial forces in both ahead and astern running.

The Metalastik double cone flexible coupling, illustrated in Fig. 7, is a heavy-duty design which is suitable for a 130 h.p. Diesel marine engine. The metallic parts are conical in shape with the rubber bonded between them. This is another example of the wise use of combined stresses to pro-

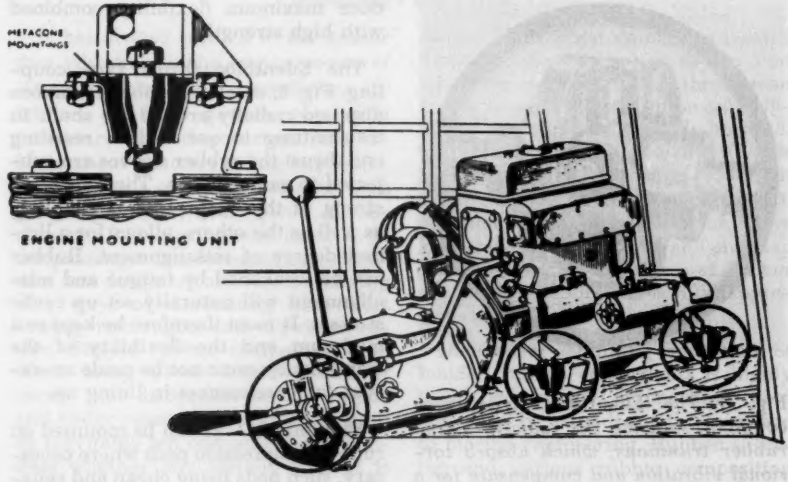


Fig. 6—*The Metacone system for flexibly mounting a small marine engine; also rubber type couplings*

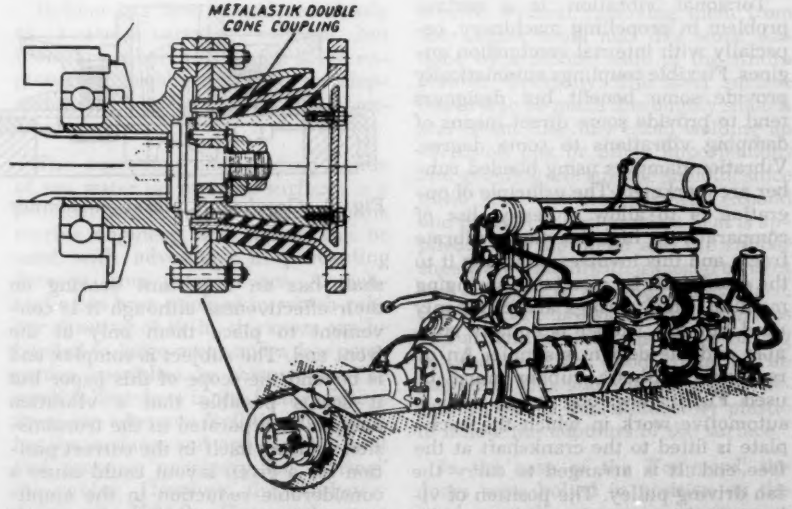


Fig. 7—*The Metalastik double cone flexible coupling, which carries thrust load*

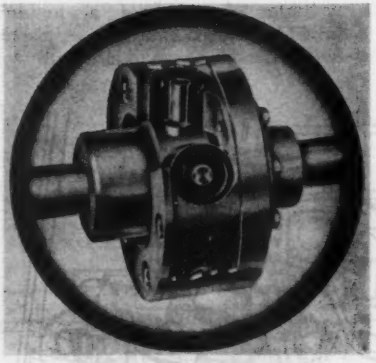


Fig. 8—*The Silentbloc thrust type coupling, showing the radially placed rubber trunnions, which absorb torsional vibration and compensate for a limited amount of misalignment*

duce maximum flexibility combined with high strength.

The Silentbloc thrust type coupling. Fig. 8, employs rubber trunnions disposed radially around the shaft. In transmitting torque and in resisting end thrust the rubber sleeves are subjected to radial forces. They are very strong in this respect. This coupling, as well as the others, allows for a limited degree of misalignment. Rubber can be weakened by fatigue and misalignment will naturally set up cyclic stresses. It must therefore be kept to a minimum and the flexibility of the transmission must not be made an excuse for carelessness in lining up.

Plummer blocks can be mounted on rubber compression pads where necessary, such pads being cheap and reliable.

TORSIONAL VIBRATION

Torsional vibration is a serious problem in propelling machinery, especially with internal combustion engines. Flexible couplings automatically provide some benefit but designers tend to provide some direct means of damping vibrations to some degree. Vibration dampers using bonded rubber are marketed. The principle of operation is to allow a heavy disc of comparatively high inertia to vibrate freely and this involves attaching it to the crankshaft by a suitable springing medium. Steel springs are commonly used but soft rubber is equally suitable and the design is simple. An oil resistant synthetic rubber must be used. Fig. 9 shows one design used in automotive work in which the backplate is fitted to the crankshaft at the free end. It is arranged to carry the fan driving pulley. The position of vibration dampers along the crankshaft has an important bearing on their effectiveness although it is convenient to place them only at the front end. The subject is complex and is beyond the scope of this paper but it seems possible that a vibration damper incorporated in the transmission shafting itself in the correct position for a given layout could cause a considerable reduction in the amplitude of torsional vibration.

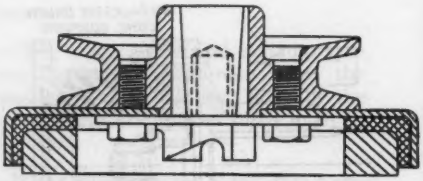


Fig. 9—*Crankshaft vibration damper*

INSTRUMENT MOUNTING

It has always seemed to the author that vibration in the engine rooms of larger vessels is given insufficient attention. Pressure gauges, revolution indicators and other instruments vibrate about a mean reading and sometimes lengths of piping resonate with the frequency of some piece of machinery. In motoring, the comfort of the passenger is a foremost consideration and designers are forever finding new ways of eliminating discomfort arising from engine and vehicle vibration. Simple rubber components can often bring about improvement. It seems that discomfort in the engine and boiler rooms of a ship is accepted as inevitable but one sometimes wonders whether any serious attempt is made to reduce it to a minimum. Vibration can assume many forms, and can do many kinds of damage. Mechanical damage is well known and every designer is alert to such a possibility but human damage is treated casually. Research has shown that vibration is fatiguing to the human frame, impairs concentration and efficiency and may be physically harmful. Continuous noise, especially if it is high-pitched, is a type of vibration which can be very objectionable. In passenger ships, vibrations of many kinds must be considered and one may ask whether the usefulness of rubber in vibration absorption is fully appreciated by ship designers.

Instrument mounting by means of bonded rubber components is highly developed in the aeronautical field and could be extended with advantage to marine engineering. Rubber sheeting and various rubber composition materials might be applied to bulkheads, deck and machinery casings to lessen noise and other vibration, and the cost of such improvement would be very small.

CORROSION RESISTANCE

Rubber has been considered chiefly as a stress-carrying material but there are other uses which solve engineering problems. Three developments will be described by way of example.

The corroding and eroding action of sea water on metallic surfaces is a problem which continually faces the marine engineer, and rubber can be used with advantage in preventing damage from these causes. A technique has been evolved by which rubber sheeting of ⅛-in. thickness can be bonded to large areas and a few companies specialize in this work. The work is best done in the factory where there are adequate facilities for cleaning the surfaces and applying the heat and pressure necessary for "curing" the rubber. However, the condenser doors of H.M.S. *Vanguard* were treated without removing them from the engine room and this work was done by a mobile team of the Andre Rubber Company. The steel surface has first to be made thoroughly smooth and clean; this may entail welding up corrosion pits or other imperfections and grinding the surface smooth, since quite small air bubbles will expand and prevent adhesion when heat is applied. Both the metal and the rubber sheets are coated with a special cement and a degree of adhesion takes place. Special care is taken with overlaps and around protrusions. Hand rolling is used to effect good contact. The rubber at this stage is not fully vulcanized and is thus sufficiently plastic to follow the contours of the surface.

In the case of the *Vanguard*, the doors were bolted in position on the condenser, the various openings were

sealed and the ship's own steam supply was used to effect the vulcanization of the rubber. A careful inspection of the work was carried out to make certain that there were no imperfections in the surface through which sea water could penetrate, and an electric spark method was used to locate the imperfections. They may be easily repaired.

THE CUTLESS BEARING

In the stern tube bearing of the Cutless type, rubber is used as the wearing surface. Here the good resistance to abrasion and low coefficient of friction of wetted rubber are the properties which recommend its use. The B. F. Goodrich Company in the United States of America and the British Tire and Rubber Company in Britain are specialists in this application of rubber.

The rubber is inserted in segments with bronze backing which are dovetailed into the main housing. The segments are easily renewable. It is said that the frictional resistance of this type of bearing is comparable with that of roller bearings. There is no shortage of the necessary lubricant, water, and the presence of sand and grit is not so detrimental as in hard-surfaced bearings. Up to fifteen times the life of an orthodox bearing has been recorded and the cushioning effect of the rubber cuts down vibration and noise even when the bearing is worn.

CONDUCTIVE RUBBER

We think of rubber as an almost ideal insulator but a recent development is electrically conductive rubber. The property of conductivity is obtained by incorporating in the rubber a special type of acetylene black. When an electrical potential is applied between two points, current flows through this carbon structure. Often aluminum foils are embedded in a panel of this rubber to assist the flow of electricity.

This development interests a number of engineers. The aeronautical engineer can use it to prevent ice formation and the build-up of static charges. In printing machinery, static electricity makes the paper hard to handle and this problem can be eliminated by the use of conductive rubber. In explosive atmospheres, static charges set up on rubber belting can be dangerous and can now be avoided. Conductive rubber can be used to lag pipes when the temperature needs to be closely controlled.

In heating and refrigeration engineering, the development is specially welcome. In space heating, large low-temperature panels are preferable to small high-temperature elements, and in the U.S.A. this application is well established. Large panels of pleasantly decorated effect are attached to the walls and operate between 100 and 150 deg. F.

Conductive rubber is being applied to marine work. It can maintain a constant temperature in a ship's hold when used in conjunction with simple thermostatic controls; cabin heating is a similar application. In refrigeration work it can prevent condensation.

It has been shown that rubber can fairly be classed as an engineering material. The paper has emphasized the

importance of rubber in its highly-stressed form only because the author, being a mechanical engineer, is particularly interested in that type of application. But the problems of the engineer, whatever his field of interest, are many and varied. He is concerned with corrosion as well as fatigue; with human comfort as well as mechanical reliability; with aesthetic as well as functional requirements. To solve his problems he must gather as many materials into his net as he can—plastics, timber, leather, ceramics and rubber as well as metals. And to use these materials effectively, he must know something of their properties and characteristics, enough to guide him when occasion demands to the specialists in those materials.

Rubber is a newcomer to some fields of engineering. Prejudice lingers on regarding some of its applications and prejudice often springs from lack of knowledge. This paper has attempted a quick glance at a wide field and it is hoped that the view has been sufficient for its purpose.

DISCUSSION of AIR CONDITIONING AFLOAT—RECENT DEVELOPMENTS

by

A. S. PANELLA and E. H. HONEGGER

Page 63 Vol. 66 No. 1 February 1954

E. I. du PONT de NEMOURS & COMPANY
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LEGAL DEPARTMENT

March 24, 1954

American Society of Naval Engineers, Inc.
605 F Street, N.W.
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Gentlemen:

We notice that the February, 1954, issue of the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS contains an article by Mr. A. S. Panella and Mr. E. H. Honegger entitled "Air Conditioning Afloat—Recent Developments." In this article du Pont's trade-marks "Freon" for fluorinated hydrocarbon refrigerants, "Freon-11" for trichloromonofluoromethane and "Freon-12" for dichlorodifluoromethane are frequently used as if they were descriptive or generic terms.

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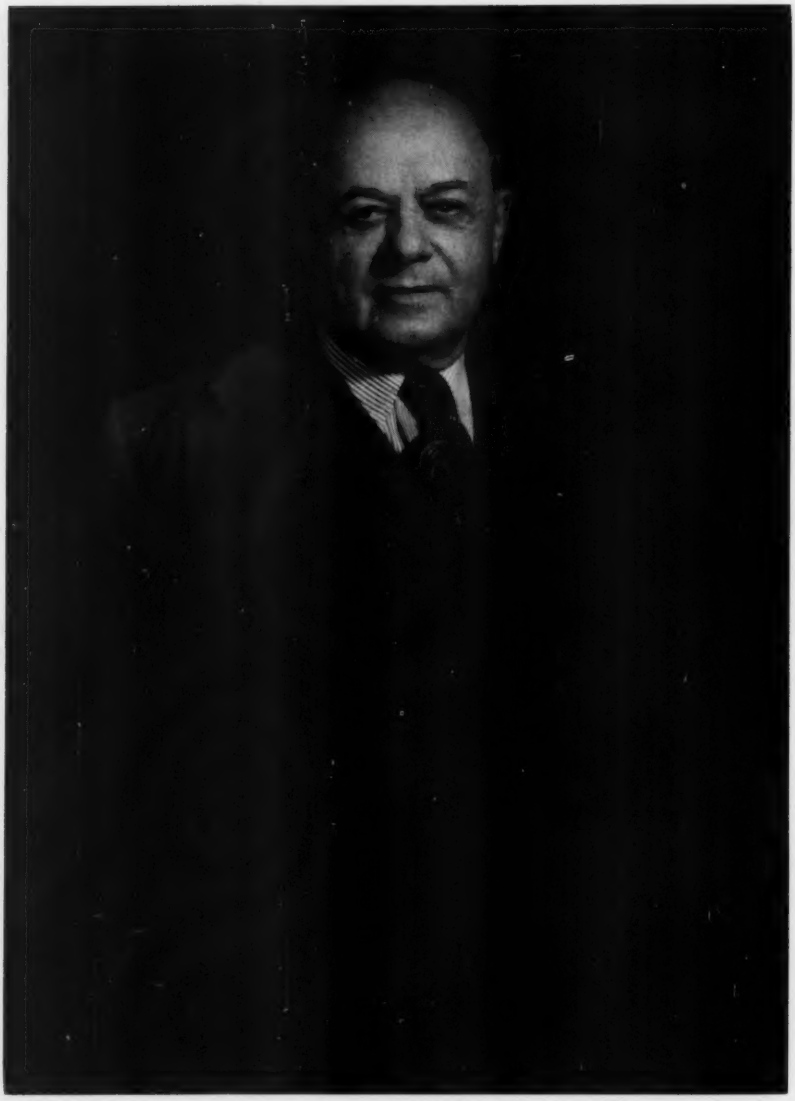

Courtesy Electric Boat Division of General Dynamics Corp.

DAVID STARK NEWELL

DAVID STARK NEWELL

The American Society of Naval Engineers joins a host of mourners over the death of David Stark Newell, Chairman of the Board of the Bath Iron Works, Bath, Maine. Mr. Newell joined the Society in 1902 and served as a member of its Council in 1941.

Mr. Newell's career was so broad, his contribution to the United States in peace and war and to its allies in war so great, his life so full that any attempt to describe them in a few words proves impossible.

In "Pete" Newell's death, the Society loses an old, steadfast and loyal member; the nation loses a MAN.

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